BENTHIC INVERTEBRATE SURVEY OF THE ST. MARY'S RIVER, 1985

VOLUME 1 - MAIN REPORT

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Water Resources Branch
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VOLUME 1 - MAIN REPORT

Report prepared for:

Great Lakes Section
Ontario Ministry of the Environment

In consultation with

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FOREWORD

by: Yousry Hamdy

The St. Marys River sustains a variety of water uses. It is a source of water supply to sizeable urban and industrial areas in both Ontario and Michigan, is a major tourist attraction and provides a vital habitat for many fish species. The Ontario Ministry of the Environment is therefore focusing its efforts to permit the greatest number of uses based on the best interests of the people of Ontario.

Several environmental studies, such as those by Hamdy et al (1978) and Hamdy and LaHaye (1984) have focused on the assessment of the effects of Ontario industrial (Algoma Steel Corp. Ltd. and St. Marys Paper), and municipal (the easterly and westerly Sault Ste. Marie sewage treatment plants) discharges.

Contaminants such as phenols, ammonia, cyanide, iron and zinc - attributable mainly to Algoma Steel discharges, are generally restricted to the Ontario shoreline of the river. Levels along the Michigan side of the river are similar to those observed at the river headwaters. Upon the completion of the redevelopment of Great Lakes Power Limited in 1982, the river flow along the Ontario shoreline increased from 21% to 36% of the total river flow. This increase is in part responsible for the reduction of phenol, ammonia and cyanide in the river during recent years.

Investigations of the river sediments revealed that contaminants such as oil and grease and heavy metals are still prevalent along the Ontario side of the river. However, data from sediment core samples collected during the Upper Great Lakes Connecting Channels Study indicates that DDT, PCBs, polynuclear aromatic hydrocarbons, zinc, chromium and lead inputs have been reduced over the past 20 years.

The Upper Great Lakes Connecting Channels Study as well as the St. Marys River MISA pilot site investigations will provide further insight into the fate and pathways of trace organics in the river ecosystem.

Contaminated sediments are a possible source of contaminants to benthic organisms and can exert toxic influences on them, either completely eliminating benthic populations or reducing the diversity to a few tolerant species. However, an Ontario Ministry of the Environment study (Persaud et al, 1987) found that biological uptake of copper, zinc and mercury was evident at locations which exhibited the lowest bulk sediment contaminant concentrations.

The present report on the 1985 benthic invertebrate survey of the St. Marys River was prepared by Beak Consultants Ltd. and is based on benthic invertebrate and sediment chemistry data collected from 70 stations in the river from Point aux Pins Bay to Lake George.

Characteristics of the benthic community structure of the St. Marys River can be described in terms of the following impairment zones:

1. Severe:

   This zone is found in the Algoma Slip area and in embayments downstream from the industrial and municipal discharges along the Ontario shoreline of the river. This zone is characterized by extreme túbificid dominance.

2. Moderate:

   This zone, mainly confined to the Ontario shoreline, is approximately 500 m wide, extending 4 km downstream from the industrial and municipal discharges. Tubificid dominance with high densities of nematodes and facultative chironomids are the major characteristics of this zone.

3. Slight:

   Some recovery was apparent with increased distance from industrial and municipal discharges; however, complete recovery was not apparent until the lower section of Lake George. Nematode and polychaete dominance with moderate densities of tubificids and some non-tolerant groups are present.

4. Unimpaired:

This zone was found in the upper reaches of the river and along the Michigan side of the river. Communities tended towards chironomid dominance, with several non-tolerant groups (e.g., ephemeropterams and trichopterans) present, together with low tubificid densities and high numbers of taxa.

It was generally observed that areas with visible oily residues were characterized by the absence of ephemeropteran Hexagenia. Substrates collected from Lake George in 1985 were contaminated by oily substances, similar to the pattern indicated by Hiltunen and Schloesser (1983).

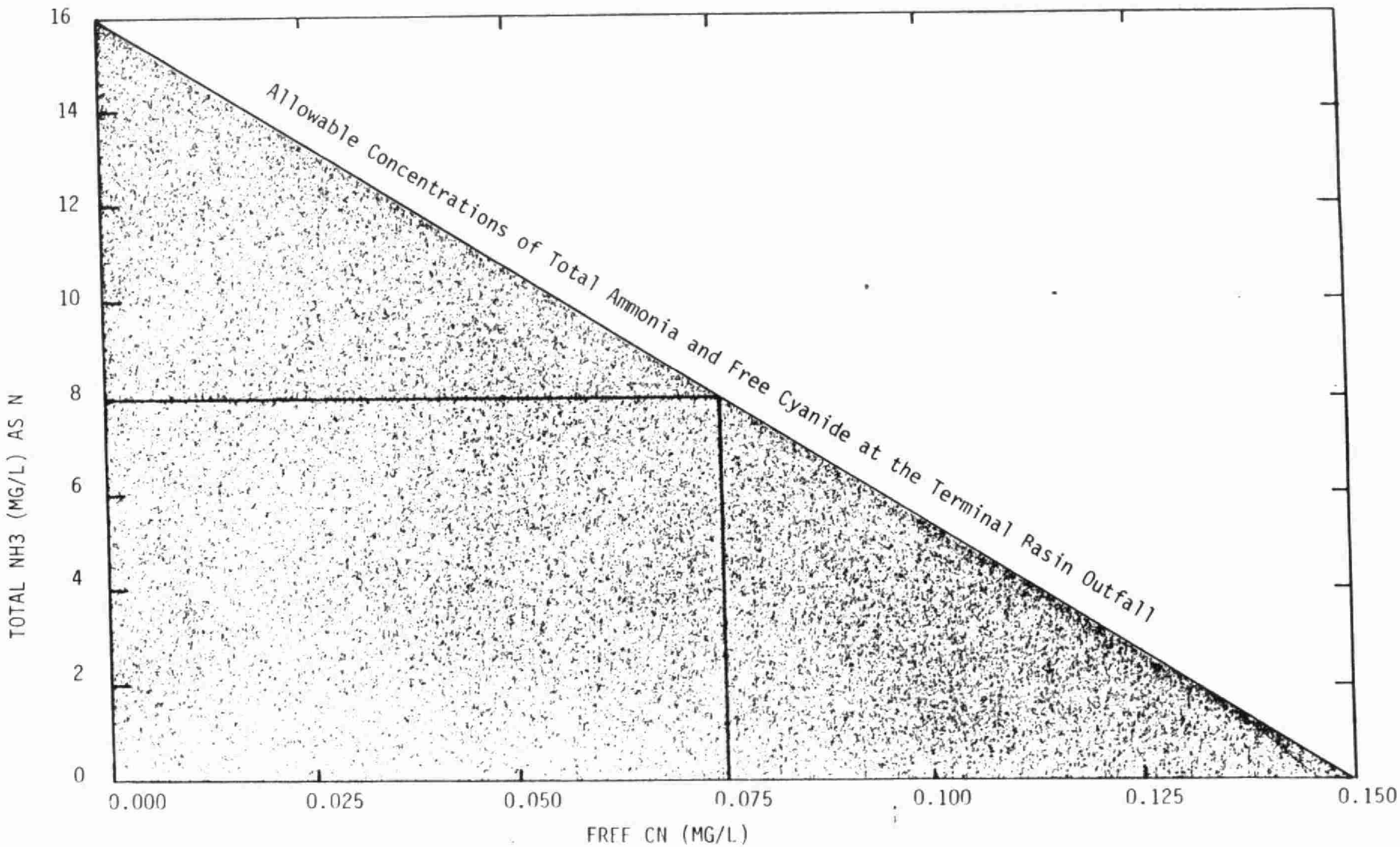
Notwithstanding recent reductions in pollutant loadings, especially those associated with Algoma Steel Corp. Ltd., no significant changes in the status of benthic communities took place along the Ontario shoreline of the river since the earlier studies (1968-1973).

Algoma Steel Corporation Limited was served with an Amending Control Order to limit discharges of phenol, ammonia, cyanide, suspended solids and ether solubles (oils and greases). The following outlines effluent requirements and associated dates when these requirements should be met:

- By March 31, 1990 ether solubles loading must not exceed 1023 kg/d and suspended solids will not exceed 5108 kg/d.
- By June 30, 1989 Algoma will reduce phenol loadings to 22.7 kg/d.
- By June 30, 1988 ammonia and cyanide levels will be at or below the level graphically illustrated by the diagonal line in Schedule 1.

SCHEDULE 1

ALLOWABLE CONCENTRATIONS OF TOTAL AMMONIA AND FREE CYANIDE AT THE TERMINAL BASIN OUTFALL



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The contract officer (P.B. Kauss) gratefully acknowledges the following:

- Field staff of Great Lakes Section for logistical support and assistance with sampling.

- Mr. B. Bowman of the Ministry's Northeastern Region Office in Sudbury for contributions to the survey design.

- Staff of the Trace Organics and Inorganic Trace Contaminants Sections of the Ministry's Rexdale laboratories for sample analyses.

- Ms M. Kirby and Mr. Y. Hamdy (Great Lakes Section) for review and constructive comments of the draft report.

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* Available upon request from the Ontario Ministry of the Environment, Water Resources Branch, Toronto, Ontario.

SUMMARY AND RECOMMENDATIONS

A study was undertaken in 1985 to examine spatial and temporal trends in the structure of the benthic community of the St. Marys River in relation to sediment contamination and wastewater sources in the vicinity of Sault Ste. Marie, Ontario and Sault Ste. Marie, Michigan. This survey concentrated on the lower river (Lake George, Little Lake George, Lake Nicolet) and in the upper river in the vicinity of Algoma Steel, as mid-river locations had been relatively intensely sampled in 1983. Some of the stations sampled in 1983 were resampled in 1985 to determine the compatibility of the two data sets.

The water quality of the St. Marys River has been impaired along the Canadian shore by discharges of organic and inorganic contaminants from pulp and paper and steel mill industries (St. Marys Paper and Algoma Steel, respectively), and the municipal sewage treatment plant (STP). Benthic surveys in 1968 and 1973 demonstrated zones of severe impairment along the Canadian shoreline downstream of the various discharges. Subsequent to these surveys, considerable progress has been made by industry in reducing contaminant loadings to the river. The 1983 benthic survey indicated that while some minor improvements had occurred, zones of severe impairment were still apparent along the Canadian shoreline.

The benthic survey detailed in this report was carried out in September/October 1985. Surficial sediment samples were collected concurrently and submitted for physical and chemical analyses, and a summary of the analytical results is provided in this report. A detailed listing of the results of these analyses will be reported in a forthcoming document prepared by the Ministry of the Environment. Benthic samples were collected in triplicate at 70 stations between Point aux Pins Bay and Lake George. Most stations were sampled using a Ponar grab and a 200 um mesh sieve, although, at a few stations, the sediments were too coarse and were sampled by an airlift sampler/200 um mesh sieve combination. Additional samples were collected at the 11 stations common to the 1983 and 1985 surveys to evaluate the effects of sampling method (ponar or airlift) and mesh size (200 um vs 500 um mesh) on the results. Benthic organisms from each sample were sorted from the debris retained by the sieve, identified and enumerated.

Data from the 1985 St. Marys benthic survey were not amenable to pooling with those of the 1983 survey, although the surveys were conducted at the same time of year. Total densities were found to be generally greater in 1985, more so at some stations than others. Different sorters and sorting methods were identified as significant contributing factors. A principal components analysis suggested that a faunal shift in species associations, either real or sorter-related, had also occurred between the two survey years.

As in 1983, the tubificid community associated with outfall areas was still apparent in 1985. Nematodes also reached high densities in all but the most severely enriched locations. General reductions in pollutant loadings from the Algoma Steel terminal basin and the St. Marys Paper operations since 1973 appear to have contributed to minor community changes, but were not reflected in major improvements in the pollutional status of the benthic community.

Cluster analysis based on species composition in 1985 showed that benthic communities characterized by tolerant species occurred in areas downstream of discharges, and other communities characterized by intolerant species occurred in areas remote from point source effects. Similar impact zones can be derived from a community index reflecting dominance of nematodes and immature tubificids without setae. Discriminant analysis identified a heavy metal-particle size gradient and a pesticide-particle size gradient in sediment quality, which together provide a basis for separation of impacted station clusters from each other and from unimpaired stations.

Impacted stations generally occurred downstream of the Algoma Steel, St. Marys Paper and easterly Sault Ste. Marie sewage treatment plant (STP) discharges. Some recovery was apparent with increasing distance downstream from the Algoma Steel and St. Marys Paper discharges; however, complete recovery was not apparent until the lower section of Lake George. The combined impact of effluents from all sources was still evident in Lake George, some 24 km downstream from the Algoma Steel and St. Marys Paper discharges. In general, impacted locations were restricted to the Canadian portion of the St. Marys River, with a clean water fauna characterizing the relatively unindustrialized U.S. shore and all portions of the river upstream of pollution sources.

The distribution of Hexagenia nymphs was found to be influenced by the occurrence of visible oil in the substrate of the St. Marys River, Lake Nicolet, and the Lake George Channel downstream into Lake George. Generally, absence or low densities of nymphs coincided with the presence of oil in the sediments. The pattern observed in 1985 for the distribution of oil and Hexagenia was similar to that reported in 1975, which indicated the occurrence of oil as far downstream as the upper half of Lake George.

Based on the results of this survey, three recommendations for future environmental monitoring can be made:

1. A benthic survey on the St. Marys River should be repeated in approximately 5-10 years to document any changes in the benthic community in response to on-going pollution abatement programs.

2. In view of the limited benthic community response to pollution abatement over the past few years, analysis of temporal trends in sediment quality, and of direct organism responses (e.g., bioaccumulation, toxicity), should be undertaken. (Such studies were initiated in 1986.)

3. In order to improve data comparability between benthic surveys a set of basic guidelines regarding sampling design, sampling methods and sorting techniques should be developed. In addition, QA/QC requirements applicable to benthic surveys should be developed to check for systematic bias between laboratories and sorters. This recommendation applies to benthic surveys in general.

SOMMAIRE ET RECOMMANDATIONS

En 1985, on a entrepris une étude dans le but d'examiner, dans l'espace et dans le temps, les tendances relatives à la composition du benthos dans la rivière St. Marys au regard de la contamination par les sédiments et des sources d'eaux usées dans les environs de Sault Ste. Marie (Ontario) et de Sault Ste. Marie (Michigan). Cette étude a porté principalement sur la basse St. Marys (lac George, Petit lac George, lac Nicolet) et sur la haute St. Marys dans les environs de la société Algoma Steel, étant donné que le cours moyen de la rivière avait fait l'objet de prélèvements relativement nombreux en 1983. On a effectué en 1985 des prélèvements à des postes qui avaient déjà été étudiés en 1983 afin de déterminer la compatibilité des deux séries de données obtenues.

La qualité de l'eau de la rivière St. Marys s'est détériorée le long des rives canadiennes en raison de déversements de polluants organiques et inorganiques provenant de l'usine de pâtes et papiers St. Marys Paper, de l'aciérie Algoma Steel et de l'usine d'épuration des eaux d'égout de Sault Ste. Marie. Des études benthiques menées en 1968 et 1973 ont révélé la présence de zones fortement polluées le long des rives canadiennes en aval du lieu des déversements. À la suite de ces études, les pollueurs en cause ont pu réduire considérablement leurs déversements dans la rivière. L'étude benthique de 1983 a révélé que malgré certaines améliorations mineures, des zones fortement polluées subsistaient le long des rives canadiennes.

L'étude benthique dont les détails figurent dans le présent rapport a été effectuée en septembre et octobre 1985. Des échantillons de sédiments superficiels ont été prélevés et soumis à des analyses physiques et chimiques dont les résultats sont résumés dans le présent rapport. La liste détaillée de ces résultats figurera dans un document ultérieur du ministère de

l'Environnement. Des échantillons de benthos ont été prélevés à trois reprises à 70 postes entre la baie Pointe aux Pins et le lac George. À la plupart des postes, les prélèvements ont été effectués à l'aide d'une pince Ponar et d'un tamis à mailles de 200 um; à certains postes, les sédiments étaient trop grossiers et il a fallu utiliser une suceuse à air combinée à un tamis à mailles de 200 um. On a prélevé des échantillons supplémentaires aux 11 postes communs à l'étude de 1983 et à celle de 1985 afin d'évaluer les effets de la méthode d'échantillonnage (par pince Ponar ou suceuse à air) et du tamis (200 um ou 500 um) sur les résultats. Les organismes benthiques de chaque échantillon étaient extraits des débris retenus par le tamis, puis identifiés et dénombrés.

Les données de l'étude benthique de la St. Marys effectuée en 1985 n'ont pu être combinées à celles de l'étude de 1983, bien que les deux études aient été menées environ à la même période de l'année. Les densités totales, en particulier à certains postes, se sont révélées plus élevées en 1985. À cet égard, l'utilisation de matériel d'échantillonnage et de méthodes de triage différents ont été considérés comme des facteurs déterminants. L'analyse des composantes principales a permis de constater qu'une modification des associations d'espèces, réelle ou causée par le triage, s'était produite entre les deux études.

Comme en 1983, la présence de Tubificidae dans les zones de déversement était décelable en 1985. Les nématodes se trouvaient également en forte densité, sauf dans les zones les plus polluées. La réduction générale de la quantité de polluants déversés du bassin terminal de l'aciérie Algoma Steel et de l'usine de la société St. Marys Paper depuis 1973 semble avoir entraîné certains changements mineurs, mais non pas de diminution importante de la pollution du benthos.

En 1985, une analyse typologique fondée sur la composition des espèces a montré que les communautés benthiques comportant des

espèces résistantes à la pollution se trouvaient dans les zones situées en aval des points de déversement, et que les communautés composées d'espèces non résistantes se situaient dans les zones éloignées des sources ponctuelles. Des zones touchées semblables peuvent être déterminées à partir d'un indice reflétant la prépondérance des nématodes et des Tubificidae sous-développés sans soies. L'analyse discriminante a permis de caractériser les sédiments selon la taille des particules de métaux lourds et de pesticides qu'ils contiennent, ce qui constitue un moyen de distinguer les postes touchés à la fois entre eux et par rapport aux postes non touchés.

La plupart des postes touchés étaient situés en aval des points de déversement de l'aciérie Algoma Steel, de l'usine St. Marys Paper et de l'usine de traitement des eaux d'égout de Sault Ste. Marie, à l'est. Plus loin en aval de l'aciérie et de l'usine de pâtes et papiers, une certaine diminution de la pollution a été constatée; cependant, ce n'est qu'à partir de la section sud du lac George que la qualité de l'eau revenait à la normale. L'incidence combinée des effluents de toutes sources était encore décelable dans le lac George, à environ 24 km en aval des points de déversement de l'aciérie et de l'usine de pâtes et papiers. Dans l'ensemble, les zones touchées étaient situées dans la partie canadienne de la rivière St. Marys (une faune d'eau non polluée se trouvait le long des rives étatsuniennes, relativement peu industrialisées) et dans toutes les parties de la rivière en amont des sources de pollution.

La répartition des nymphes d'Hexagenia s'est révélée influencée par la présence d'huile visible dans le substrat de la rivière St. Marys, du lac Nicolet et du canal du lac George en aval jusqu'au lac George. L'absence ou la faible densité de nymphes correspondait généralement à la présence d'huile dans les sédiments. La répartition de l'huile et des Hexagenia observée en 1985 était semblable à celle qui avait été relevée lors d'une étude effectuée en 1975 et qui avait établi la présence d'huile en aval jusque dans la première moitié du lac George.

Des résultats de l'étude, découlent trois recommandations relatives à la surveillance environnementale :

1. Il convient de refaire une étude benthique de la rivière St. Marys dans 5 à 10 ans afin de déterminer si les programmes d'assainissement en cours ont entraîné une modification du benthos.

2. Étant donné le peu d'amélioration du benthos constaté depuis quelques années malgré les mesures d'assainissement, il convient d'entreprendre l'analyse des tendances temporelles de la qualité des sédiments et l'analyse des effets directs sur les organismes (p. ex., bioaccumulation, toxicité). Des études de ce genre ont été entreprises en 1986.

3. Afin d'améliorer la comparabilité des données des différentes études benthiques, il convient d'élaborer un ensemble de lignes directrices fondamentales portant sur le plan et les méthodes d'échantillonnage et sur les techniques de triage. En outre, il y a lieu d'établir des normes d'assurance et de contrôle de la qualité touchant les études benthiques afin de vérifier s'il se produit des écarts systématiques entre les laboratoires et les appareils d'échantillonnage. Cette recommandation s'applique aux études benthiques en général.

1.0 INTRODUCTION

1.1 Background and Objectives

The maintenance of a high level of water quality in the St. Marys River is one of the major concerns in the upper Great Lakes system. The river is a source of water supply for a sizeable urban and industrial area in both Ontario and Michigan, is a major tourist attraction and provides a vital habitat for many important fish species. Therefore, degradation of water quality can have serious implications for water use in both Canada and the United States.

Pollution resulting from steel and paper mill discharges has been documented since the 1940's and has been manifested in impairment of water quality, sediments and the zoobenthos. The Ontario Water Resources Commission (OWRC), in cooperation with the International Joint Commission (IJC), conducted a survey of the impacted benthic community in 1967 (Veal, 1968). Considerable progress has, however, been made since 1970 by Algoma Steel Corporation in reducing phenol discharges, by Abitibi Paper (now St. Marys Paper) Company Ltd. in reducing suspended solids loadings, and by Sault Ste. Marie, Ontario in improving the removal of settleable organic matter from the municipal sewage treatment plant.

As part of Ontario's contribution to the three-year International Reference Study on the pollution problems of Lake Huron and Lake Superior, the Ontario Ministry of Environment (MOE) intensified assessment activity in the river in 1973 and 1974 for the purposes of:

- o determining the water quality status in light of improvements in waste treatment;
- o predicting the ultimate effectiveness of ongoing remedial measures in restoring river water quality; and
- o investigating the need for further remedial actions.

Information was also required to assess water quality in terms of IJC Agreement objectives and to investigate the transboundary movement of pollutants.

Results of a 1973 benthic survey (Hamdy et al., 1978) indicated little improvement since 1967 in the benthic community. Zones of severe or strong impairment were identified adjacent to and downstream of the Algoma Steel, Abitibi-Price and Sault Ste. Marie STP discharges (Figures A1.1 and A1.2, Appendix 1). As a result of this study, further reductions in waste loading and additional follow-up studies were recommended.

IEC Beak Consultants Ltd. (IEC BEAK), under contract to the MOE Great Lakes Section undertook a benthic and sediment survey of the St. Marys River in the autumn of 1983 (McKee et. al., 1984). The purpose of this survey was to examine sediment quality/benthological relationships in light of changing hydrological conditions brought about by recent reconstruction of the Great Lakes Power Corporation generating station and ongoing pollution abatement programs at Algoma Steel.

It was concluded that the benthic communities of the St. Marys River in 1983 were generally similar to those found in 1968 and 1973, with zones of severe or moderate impact adjacent to and downstream of the pulp and paper mill, steel mill and sewage treatment plant discharges. A severely impacted community characterized by high densities of Limnodrilus/Tubifex reported earlier was less pronounced in 1983, and the severe impact zone was confined to a region downstream of St. Marys Falls (Figure A1.3, Appendix 1). This has been identified as a region of heavy metal contamination. Reductions in pollutant loadings by industry appeared to have contributed to the minor community changes. No impacts from transboundary transport of contaminants were apparent in the benthic community along the Michigan shoreline.

The 1983 survey was less extensive than in earlier years, with little or no sampling downstream of the industrial region in Lake George, Little Lake George or Lake Nicolet, or upstream of Algoma Steel to Whitefish Bay. Since benthic community effects were still apparent throughout the industrial region, additional sampling in the upstream and downstream areas was recommended to define their full extent. On the basis of a survey by Hiltunen and Schloesser (1983) in 1974-75, the benthic community is believed to be impacted to a point at least 30 km downstream of Sault Ste. Marie due to oily substances in the sediments.

Accordingly, the Ministry of Environment (Water Resources Branch, Great Lakes Section) sponsored a 1985 survey to augment the 1983 results. While emphasis was placed on the

lower and upper rivers, some of the 1983 stations were resampled in 1985 to determine the comparability of 1983 and 1985 data. This report documents the results of the 1985 benthic survey, compares the 1985 data with those from the earlier studies, and evaluates relationships between sediment quality and benthic community structure.

1.2 Description of Study Area

The St. Marys River is the connecting waterway between Lake Superior and Lake Huron. The upper portion of the river extends from Whitefish Bay to the St. Marys Falls. A series of works (locks, power diversion channels, regulating gates) have been constructed as aids to control the outflow of Lake Superior for navigation and for power development.

The lower river has an irregular shoreline and contains three large islands, Sugar and Neebish Islands on the U.S. side and St. Joseph Island on the Canadian side. Sugar Island diverts the river below the locks into two channels, Lake Nicolet and Lake George (Figure 2.1A). St. Joseph Island subdivides the flow from Lake George into the middle and east channels, while Neebish Island subdivides the flow from Lake Nicolet into middle and west channels.

Geology and Topography

The rock formations of the land bordering the St. Marys River consist of schists, granite and diabases of Precambrian age which are mantled and in places deeply buried underneath glacial drift. The area on the Canadian side which borders the St. Marys River is a drift-covered strip from one to five miles in width. The land surface rises toward the north in a succession of terraces and reaches a maximum altitude of about 120 m above the mean water surface elevations of both Lake Superior and Lake Huron which are 180 m and 175 m above sea level, respectively. On the United States side, the topography is characterized by gradually rising terrain which develops into a flat area with an altitude of about 90 m above the bordering lakes.

Water Uses

Domestic Water Use - The Upper St. Marys River is the source of supply for the U.S. and Canadian cities of Sault Ste. Marie. The total average pumpage from the river is about

0.4 m^3/s, from a new intake situated at Gros Cap, Ontario and about 0.2 m^3/s for Sault Ste. Marie, Michigan from the river upstream of the locks. No public water supply is taken from the lower St. Marys River. The majority (approximately 70%) of Sault Ste. Marie, Ontario is supplied by wells.

Industrial Water Use - Algoma Steel and the St. Marys Paper Company withdraw about 6.4 and 0.8 m^3/s respectively from the river.

Hydroelectric Power- The Great Lakes Power Corporation Plant (Ontario), located between the Canadian lock and the mainland, used approximately 400 to 500 m^3/s in 1973 and 930 m^3/s in 1983, while the hydroelectric plant located between the U.S. locks and the rapids requires about 350 m^3/s. The Edison Sault (Michigan) hydroelectric power plant is served by a 4 km long canal which diverts water from a point just above the U.S. locks and delivers it to the plant.

Navigation - Vessel traffic through the locks has been heavy. However, the average number of vessels passing through the locks has decreased from 26,122 vessels in 1953 to 12,712 in 1970, 8,510 in 1985 and 8,345 in 1986. In recent years, shipping tonnage has fallen from the 1970 level of about 86 million tons of cargo to 74 million tons in 1985 and 70 million tons in 1986 (Corps of Engineers, pers. comm., June 1987). The vessels carry mainly crude oil, grain, steel, coal and petroleum products, taconite and iron ore between Lake Superior and the industrial centres on the lower lakes.

Recreation - The bays and lakes in the lower river provide areas with excellent recreational possibilities. Park use is intensive in the two parks nearest the cities of Sault Ste. Marie. There is private bathing along all parts of the river other than the immediate vicinity of the cities. The Algoma Health Unit restricts swimming in the river from the locks to Bells Point at Little Lake George. Boating and fishing are popular forms of recreation throughout the entire area.

Waste Disposal

Locations of municipal and industrial discharges into the river are shown in Figure 2.1A. Municipal waste waters from both cities are treated in primary plants with chlorination facilities. The effluent from the City of Sault Ste. Marie, Ontario is discharged to the

Lake George Channel at a rate of about 0.6 m^3/s, from the existing eastern facility. A new westerly plant (which came into operation in early 1986) discharges to the river upstream from the Algoma slag dump site at a rate of 0.24 m^3/s. The U.S. facility is the major U.S. point source discharger to the international section of the river, at a rate of 0.13 m^3/s.

Industrial waste discharges from Sault Ste. Marie, Ontario total about 7.2 m^3/s, about 90% of this from Algoma Steel. There are no industrial discharges from Sault Ste. Marie, Michigan to the river.

Trend analyses for the effluent quality of the Algoma Steel terminal basin (which discharges about 80% of Algoma Steel flows) indicated that effluent concentrations from Algoma* were reduced substantially between 1972 and 1985 (Figures A1.4 to A1.8, Appendix 1), as follows: phenolics (80%), ammonia (80%), cyanide (98%) and sulphides (99%). Total suspended solids loadings increased slightly (10%) in 1985 over 1972-73 levels, after decreasing substantially in 1982-83 from levels recorded in 1974-81. These reductions resulted in concentrations in the St. Marys River approaching the 1978 Great Lakes Water Quality Agreement (GLWQA) and Provincial Objectives (PWQ) for the protection of aquatic life (MOE, unpublished data). This decrease was likely attributable to the reduction in point source loadings, as well as an increase (approximately two-fold) in river flow along the Ontario shoreline resulting from increased diversion to Great Lakes Power in 1982. In 1985, flow rates from Lake Superior were the highest on record at 3,766 m^3/s (as compared to a mean flow of 2,140 m^3/s recorded over 1955 to 1979), with about 40% of this diverted from Lake Superior through the Great Lakes Power facility. These higher flows would tend to increase dilution of the discharges as well as to displace existing contaminated bedload sediments.

The other main industrial waste water discharge is from the St. Marys paper mill operation. This discharge takes place through the main mill sewer and the sulphite sewer. The latter, however, has been terminated. The total flow from the main mill

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* G. LaHaye, MOE, pers. comm.

sewer was 0.8 m^3/s in 1973. Effluent loadings of suspended solids and BOD_5 from St. Marys paper mill have been declining steadily since 1968. Suspended solid loadings were reduced 75% between 1973 and 1983.

2.0 METHODS

2.1 Field Survey Methods

The 1985 survey was carried out from 24 September to 04 October 1985 using the Ministry of the Environment survey vessel, "Monitor V". Stations were carefully located using the vessel's radar positioning equipment. Sampling locations are illustrated in Figure 2.1A and 2.1B. A total of 71 stations were sampled in 1985, with 11 stations corresponding to 1983 locations.

The station numbering system used started from stations sampled at the south end of Lake George, increasing upstream. Where transects were sampled, the number system denoted the distance upstream or downstream from the St. Marys Falls and the distance from the U.S. shore. For example, Station SMD 6.4E-490 indicates a location 6.4 mi downstream of the falls in the eastern channel and 490 m from the U.S. shore.

A preliminary survey completed in 1983 (McKee et al., 1984) indicated that three replicate samples at each sampling station were sufficient for estimation of log-transformed total organism density with a standard error less than or equal to 20% of the mean density. This requirement was not likely to have changed since 1983. Therefore, three replicate samples were collected at each 1985 sampling station.

Benthic samples were collected primarily by Ponar, with two stations requiring airlift sampling due to substrate characteristics. The Ponar grab sampled a bottom area of 0.05 m^2. The diver-operated airlift sampler was equipped with a 6 cm diameter opening at the intake, and 200 um mesh Nitex collecting bags. A 0.075 m^2 circular quadrat was used on the river bed to demarcate the area sampled. Invertebrates were lightly brushed by hand by diver from any rock and cobble in the sampled area and drawn into the intake of the airlift. All benthic samples were washed through 200 um mesh and were preserved in 5 to 10% formalin.

Benthic samples were then dispatched to the laboratory for sorting, identification and enumeration of benthic fauna. Benthic organisms were sorted from sediment and debris using a dissecting microscope (10x power) and grouped by major taxa. After sorting, a subsample of the tubificids ($\geq$ 20%) and chironomids ($\geq$ 10%) in each sample was cleared

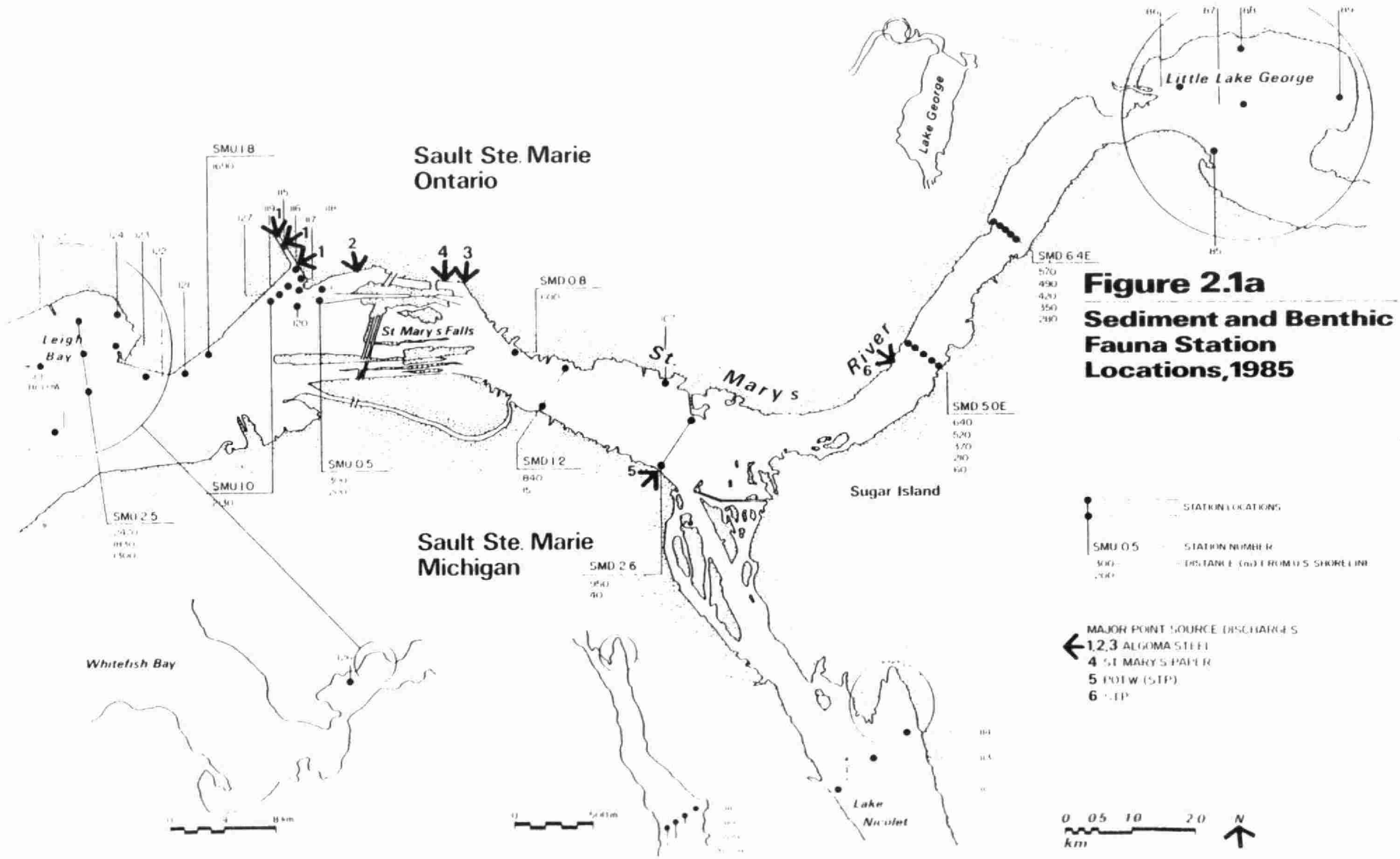

Figure 2.1a
Sediment and Benthic Fauna Station Locations, 1985

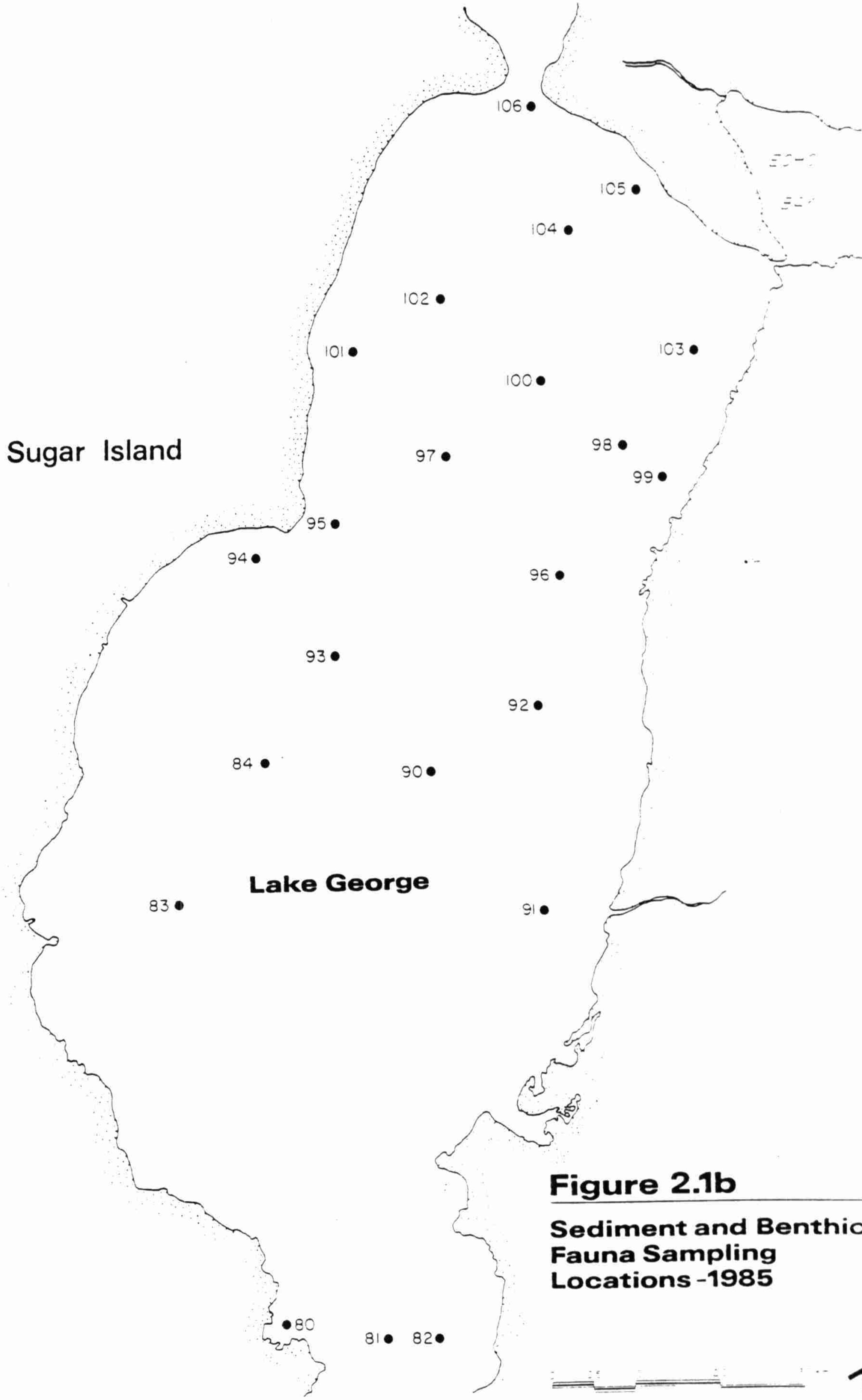

Figure 2.1b

Sediment and Benthic Fauna Sampling Locations -1985

and mounted in "CMCP-10" mounting medium on microscope slides. Chironomids were generally decapitated to facilitate clearing of the head capsule. Benthic organisms were identified using various taxonomic keys - Klemm (1985) for Oligochaeta; Oliver and Roussel (1983), for Chironomidae; Mackie et al. (1980) and Clarke (1981) for Mollusca; Wiggins (1977) for Trichoptera; and Pennak (1978) for other groups. All abundance data were expressed on a 0.05 m^2 basis.

Surficial sediments were collected at each station for physical/chemical analysis using a Shipek sampler. This device samples a 0.04 m^2 area of bottom and was subsampled to a depth of 3 cm. Depending on substrate type, three or more sediment samples were needed to provide sufficient sample volume to meet the analytical requirements. MOE also meaured Eh (redox potential) of the samples before they were removed from the Shipek sampler. The presence of any odour (i.e., phenolic) or oily sheen was noted, and sediment texture and colour were described. The presence of aquatic plants and woody debris was also recorded, along with water depth and perceived current. Sediments from each station were homogenized in a clean, solvent-rinsed stainless steel tray using stainless steel utensils. Sediments were then partitioned into subsamples for analysis of trace organic and inorganic constituents by the MOE laboratories in Rexdale. Results of the sediment analyses will be presented in a forthcoming report from the Great Lakes Section, Water Resources Branch. A summary of the data is presented herein for the purposes of examination of sediment quality-benthic community structure relationships.

2.2 Statistical Analysis

2.2.1 Comparability of 1983 and 1985 Benthic Surveys

A number of preliminary analyses were performed to assess the comparability of 1983 and 1985 survey data. Comparability would permit pooling of 1983 and 1985 data to provide a larger database for further analysis. Potential sources of data set incompatibility include:

1. differences in sampling equipment - most stations in 1983 (35 of 40 surveyed) were sampled by airlift sampler, while the others were sampled using a Ponar grab. In 1985, all but two stations were sampled by Ponar. A 200 um mesh was used for sieving in both years;

2. differences in sorting efficiency - changes in personnel between surveys could produce differences in retrieval of organisms from 1983 and 1985 samples; and
3. real changes in benthic faunal densities and associations between 1983 and 1985.

Each of these questions was separately addressed. The results are summarized below, with supporting data and statistics in Appendix 2.

Sampling Equipment

Three stations were sampled by multiple methods during the 1985 survey (SMD 5.0E-60, SMU 1.0-2130 and SMU 2.5-1830). The methods included airlift sampling with a 200 um mesh, Ponar sampling with a 200 um mesh, and Ponar sampling with a 500 um mesh (a method used in St. Marys River surveys prior to 1983). Five replicate samples were collected at each station by each method, and total organism densities were compared (Table A2.1A).

Two-way factorial ANOVA on log-transformed densities indicated a significant interaction between station and method effects ($p = 0.05$) when Ponar 500 um mesh data were included (Table A2.1B). This interaction disappeared, and methods did not differ significantly, when Ponar 500 um mesh data were excluded (Table A2.1C). Thus, Ponar and airlift sampling methods should agree as long as the same mesh size (200 um) is used in sample sieving.

Sorting Efficiency

Four samples collected in 1985 (118, SMD5.0E-210, -370 and -520), three of which were also sampled in 1983 (SMD5.0E-210, -370 and -520), were independently sorted (at the subsample level) by two different individuals in 1985. One sorter attempted to reproduce the sorting method used in 1983 (i.e., without the aid of a dissecting microscope), while the other sorter used a dissecting microscope at about 10x power (as used for all other samples sorted in 1985). Total organism densities of the subsample portions reported by these sorters, and by the 1983 sorter, for each of three replicates per station were compared (Table A2.2A), and are presented in Figure A2.1. Two-way factorial ANOVA

on 1985 log-transformed densities indicated a significant interaction between station and sorter (Table A2.2B). Thus, sorter effects vary from one station to another. They could represent a source of database incompatibility, and it would not be possible to adjust one year's data to be comparable with those of another year. Sorting done with the aid of a microscope usually resulted in a greater recovery of organisms than sorting done without.

Changes in Benthic Density

The possibility of changes in total organism density between surveys was assessed at 11 stations sampled both in 1983 and 1985 (SMD 5.0-60, -210, -370, -520, -640; SMU 0.5-200, -300; SMU 2.5-1300, -1830, -2470; and SMU 1.0-2130). Detailed results from these locations are presented in Table A2.3A (Appendix 2). Two-way factorial ANOVA on log-transformed densities indicated a significant interaction between station and year ($p < 0.05$; Table A2.3B). Densities were always higher in 1985, but the magnitude of the difference varied strongly from one station to another.

Density increases between surveys could represent real faunal changes or they could be related to the use of different sorters in different surveys. In either case, because the effect varies among stations, it is not possible to adjust one year's data to be comparable with those of another year or to combine the two data sets.

Changes in Faunal Association

Species associations were compared between surveys at the 11 stations sampled in 1983 and 1985. A Principal Components Analysis (PCA) was performed on each year's data using both log-transformed and untransformed data. This analysis is based on the matrix of correlations between densities of different species. The most distinctive group of associated species is identified as the first principal component of the benthic community. Secondary species groups, distributed independently of the others, are identified as subsequent principal components.

Patterns of species association, as represented by the plot of species 'loadings' on the first two principal components, were quite different between surveys, whether transformed or untransformed data were used (Table A2.4 and Figure A2.2 present 1983 results and Table A2.5 and Figure A2.2 present 1985 results, based on untransformed

data). Moreover, only about one-third of the key species contributors to the first principal component were common to the 1983 and 1985 surveys. This difference between surveys suggests that real or sorter-related faunal shifts have occurred, and that 1985 data should not be pooled with 1983 data for analysis of the benthic community.

Immature tubificids were treated as two distinct taxa (capilliform and non-capilliform) in principal components analysis, since at most stations where they occurred in 1985, mature tubificids were absent, preventing any logical representation of tubificid species composition. This convention was applied to both the 1983 and 1985 data sets for PCA.

2.2.2 Cluster Analysis of Spatial Patterns

The 1985 benthic communities were defined by means of cluster analysis (Anderberg, 1973; Green, 1979; Gordon, 1981). This family of techniques for pattern recognition identifies stations with similar benthic species composition, and groups biologically similar stations into clusters. The species characterizing each cluster of stations are interpreted as distinctive natural communities. In cases where pollution is an important determinant of community structure, these communities tend to be spatially distributed in relation to pollution sources.

Several cluster analysis techniques were used in order to identify robust spatial patterns which are evident by several techniques. The techniques used were as follows:

1. convergent K-means partitioning,
2. sum of squares agglomeration (Ward's method),
3. group average link agglomeration, and
4. Howard-Harris polythetic division.

The first technique is non-hierarchical and assumes a priori knowledge of the number of station clusters (i.e., faunal assemblages) in the community. As this is seldom known, a range of values for the number of clusters was tried, and the solutions were compared. Methods 1, 2 and 3 were performed using the SPSS statistical package for the IBM-XT (Norusis, 1986).

Methods 2 and 3 are hierarchical agglomerative techniques in which stations or station groups are sequentially fused according to their similarities. The process continues until

all stations are accounted for, producing a solution (i.e., station grouping pattern) at each fusion stage. Both methods are based on inverse measures of station similarity, either Euclidean distance (D) or Squared Euclidean distance (D^2). The distance formula for Stations j and k (Norusis, 1986) is:

$$D^2 (j, k) = \sum_{h=1}^{n} (X_{hj} - X_{hk})^2$$

where: X_{hj} = log-transformed abundance of species h at Station j. Method 2 (Ward's method) was based on D^2 and Method 3 on D.

Method 4 (Harris, 1985) is a hierarchical divisive technique, using the first principal component of species composition as a splitting criterion to sequentially divide the stations into increasing numbers of groups. At each stage, stations are grouped so as to minimize within-cluster variance of the principal component (i.e., maximize within-cluster similarity). Statistical software was provided by B. Harris, University of Pennsylvania.

The cluster solution producing the greatest degree of community structure was chosen to represent the St. Marys River benthic community. Structure is indicated by well-defined station clusters, internally homogeneous and dissimilar from each other. Solutions of this nature tend to be the most interpretable. Figure A3.1 (Appendix 3) illustrates the relationship between number of clusters and maximum biological distance between clusters for the hierarchical agglomerative techniques, and demonstrates the superiority of the Ward's solution. This solution shows the greatest instantaneous rate of increase in between-cluster distance, and suggests a break point or sharp increase in community structure at the seven-cluster level. Thus, the seven-cluster Ward's solution was chosen to represent spatial patterns in the benthos.

Other cluster analysis solutions are compared to the Ward's solution in Table A3.1 (Appendix 3). This comparison shows a good concordance between the seven-cluster Ward's solution and the seven-cluster Howard-Harris solution (52 of 70 stations falling within the same station clusters and, following cluster characterization, agreement on impacted vs. unimpacted status of 66 stations). Thus, the representation of 1985 spatial

pattern appears to be robust, and the cluster analysis methods used in 1983 and 1985 agree closely (see McKee et al., 1984).

Immature tubificids were treated as two distinct taxa (capilliform and non-capilliform) in cluster analysis of the 1985 data, since at most stations where they occurred, mature tubificids were absent, preventing any accurate representation of tubificid species composition.

This approach differed from the approach used in 1983 when immature tubificids were usually accompanied by mature individuals, and only the mature individuals were included in the data set.

2.2.3 Temporal Comparison of Spatial Patterns

Characterization of station clusters in 1985 was based on comparison of total organism density, species richness, tubificid dominance and species composition between clusters. This information was used to identify impacted station clusters, and from the spatial distribution of these clusters to delimit impact zones. Spatial patterns and impact zones in 1985 were related to known past and present pollution inputs, and compared to spatial patterns and impact zones during previous surveys (McKee et. al., 1984).

2.2.4 Sediment Quality Relationships of Benthic Communities

Several independent methods were used to examine the sediment quality characteristics of the St. Marys River benthic communities. First, discriminant analysis was performed on the sediment quality data in order to identify environmental gradients in sediment quality which tend to distinguish between the stations in different benthic faunal clusters (Section 2.2.2). This method has been described by Green (1979), and other authors (e.g., Hutchinson, 1978), as a means of representing the ecological niche space occupied by different communities.

A second method of examining the sediment quality - benthic faunal relationships is by derivation of a quantitative benthic community index, with a value at each station, to be used as a dependent variable in regression analysis of the sediment data. Thus, the sediment characteristics which are the best predictors of the community index can be

identified. This approach differs from discriminant analysis primarily in the nature of the dependent variable. In discriminant analysis, the dependent variable reflects cluster membership, based on overall species composition, while a community index can reflect more specific attributes of species composition in a quantitative manner.

The community index used in this approach was a measure of dominance by a particular group of taxa (or guild). Guilds were defined by R-mode cluster analysis, which groups species based on similar spatial distributions (i.e., similar densities at each station). Densities were log transformed, as in the Q-mode cluster analysis of Section 2.2.2. An index of dominance by each guild was calculated at each station as follows:

$$I_g = \frac{\sum_{i=1}^{S_g} \log (X_i + 1)}{\sum_{i=1}^{S} \log (X_i + 1)}$$

where: S_g = number of taxa in the guild,
S = total number of taxa present, and
X_i = density of species i.

The dominance index ranges from zero to one in magnitude.

Some guilds consisted of recognized pollution tolerant taxa. Their index values were plotted on study area maps to illustrate association with known point sources. Bivariate correlations with sediment variables were determined, and stepwise multiple regression analysis was performed to find the best set of sediment variables for prediction of the community index.

Some sediment variables were transformed prior to use in discriminant, correlation or multiple regression analysis, in order to improve their statistical distributions. Trace metals, pesticides, solvent extractables, total organic carbon (TOC), total Kjeldahl nitrogen (TKN) and phosphorus were log-transformed. An angular transformation was

used for particle size variables[1], and a square root transformation for loss on ignition (LOI). The pH and Eh distributions were not transformed. Water depth was included as a predictor variable, with log transformation.

Water depth and Eh values for each station are listed in Table A5.1 (Appendix 5). Values for other sediment quality variables are available from the Water Resources Branch, Great Lakes Section. Mean values for all stations and parameters are provided in Table A5.2 (Appendix 5). A few stations missing data for pH, Eh, LOI and pesticides were characterized by study area mean values of these parameters prior to transformation.

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[1] The particle size class variables used were:
Class 1: > 1000 um diameter
Class 2: 45 to 1,000 um
Class 3: < 45 um
Silt
Clay
Silt + clay

3.0 RESULTS AND DISCUSSION

3.1 1985 Survey

Species and densities of benthic organisms found at stations in the St. Marys River (densities/m^2) in 1985 are summarized in Table A4.1A (Appendix 4). Raw data (species and numbers per sample) are provided in Table A4.1B (Appendix 4). Physical, chemical and biological observations recorded at each station are presented in Table A5.1 (Appendix 5). Species assemblages are described and compared with those found in earlier surveys in Section 3.4.

Detailed sediment quality results are available from the Great Lakes Section, Water Quality Branch, and will be reported in a forthcoming document.

3.2 Indicator Species in the St. Marys River

In the following subsections, reference is frequently made to the relative tolerance or intolerance of benthic species to polluted conditions. Clean-water indicators are reported as more prevalent at locations well removed from effluent discharges, while tolerant forms prevail in the apparently impacted areas found downstream of the major point sources. The pollution tolerance of benthic invertebrates, as outlined below, typically refers to tolerance of pollution by organic matter and associated low dissolved oxygen conditions, rather then to tolerance of toxic metals and organic compounds.

Mayflies such as Hexagenia, Ephemera and Caenis are generally considered to be intolerant (Roback, 1974); Hexagenia has been reported as rare or absent in sediments contaminated by oily substances in the St. Marys River (Hiltunen and Schloesser, 1983). The lumbriculid Stylodrilus heringianus may also be considered a clean water indicator. This species prefers sandy to gravelly substrates such as found in much of the study area, but is typically absent or reduced in numbers in disturbed areas such as near urban centres (Nalepa and Thomas, 1976). Other species such as the tubificids Aulodrilus spp., Potamothrix moldaviensis and Spirosperma ferox are mesotrophic indicators, and Rhyacodrilus spp. is usually found in oligotrophic waters (Cook and Johnson, 1974); thus, these species are probably intolerant of heavy organic pollution. Nematodes apparently reach their highest densities in mesotrophic regions, indicating a low tolerance for highly

polluted habitats, and their absence in highly polluted areas such as Toronto Harbour (Golini, 1979) may be related to their inability to tolerate low oxygen conditions for extended periods of time. The polychaete Manayunkia speciosa is also considered indicative of moderate organic pollution (Poe and Stefan, 1975), but intolerant of severe organic pollution (Mackie and Qadrie, 1971). Other mesotrophic indicators include the chironomids Polypedilum, Nanocladius, Psectrocladius, Dicrotendipes and Microtendipes. Gill-breathing gastropods such as Valvata and Amnicola are common in the relatively unpolluted, shallow waters of outer Nipigon Bay (Lake Superior), but not in the inner bay where heavy organic pollution from pulp and paper wastewater is characteristic (Freitag et al., 1973); therefore, these species also appear to be relatively intolerant.

Among the pollution-tolerant forms, tubificids and chironomids are most noteworthy. High densities of the tubificids Limnodrilus spp. (including immatures without capilliform chaetae), Tubifex tubifex, Quistadrilus multisetosus and Ilyodrilus templetoni (both including immatures with capilliform chaetae) are characteristic of areas showing organic enrichment throughout the Great Lakes (Cook and Johnson, 1974; Brinkhurst and Cook, 1974). Similarly, the chironomids Procladius, Chironomus and Cricotopus are common in polluted conditions in the Great Lakes (Cook and Johnson, 1974).

There is relatively little information available in the literature regarding the impact of heavy-metal stress on freshwater benthic communities or individual species. Some data has demonstrated that the oligochaete L. hoffmeisteri is very tolerant of high concentrations of some heavy metals (Winner et al. 1980) and is often the only species present (Wenstel et al., 1977a) under such conditions. Nematodes are also indicated as tolerant of heavy metals, with some species occurring in high densities in the sand and gravel filter beds of sewage treatment plants (Pennak, 1978), where high metal accumulations would be expected. Similar data on the effects of persistent organic compounds on benthic organisms appear to be either extremely limited or unavailable.

3.3 Cluster Analysis of Spatial Patterns in 1985

Assignment of sampling stations to clusters, based on similarities in 1985 species composition, is presented in Table A3.1 and Figure A3.2 (Appendix 3).

Seven clusters were defined in 1985 (Figure 3.1) with three clusters (Nos. 2 to 4) identified as including pollution-impacted stations. The stations in these three clusters were dominated by individual indicator species or pollution-tolerant groups of species, and were associated with known industrial outfalls or downstream depositional areas. The remaining four clusters (Nos. 1, 5, 6, and 7) generally described stations that were upstream of effluent discharges, near the U.S. shoreline or well downstream of discharges. Characterization of station clusters is summarized in Table 3.1. Biological characteristics presented in this table include species common to all stations within the cluster, mean number of taxa and mean total density. Physical and chemical features include substrate type, water depth, presence of macrophytes, presence of visible oil in the sediment and current speed.

Clusters 2 to 4

The pollution-impacted clusters (2 to 4), include stations with benthic populations dominated by tubificid oligochaetes, along with nematodes and polychaetes. Most of the species present were at least moderately tolerant of the effects of organic enrichment. Cluster 4 included stations with considerable reductions in number of taxa and density, possibly as a result of toxicity from point-source discharge areas. These individual clusters are described in detail below.

Cluster 2

Cluster 2 consisted of five stations downstream of the eastern STP (SMD 5.0E-210, SMD 6.4E-350, -420, -490 and -570) and two other stations (Stations 113 at the north end of Lake Nicolet and 120 near the Algoma slip). These stations were characterized by a coarse sand substrate, with or without an overlying silt layer. Water depth was variable, ranging from 2.5 to 14 m, and current speed ranged from slight to moderate. Macrophytes were absent or very sparse at these locations, and oil was generally present, especially at SMD 6.4E-350.

Characteristic taxa were nematodes, polychaetes, nemerteans, pea clams, immature tubificids with capilliform chaetae (likely T. tubifex and/or I. templetoni), immature tubificids without capilliform chaetae (likely Limnodrilus spp.), S. ferox, and the lumbriculid worm S. heringianus. The mean number of taxa per station (23) was

Figure 3.1

Relationships between 1985 Benthic Station Clusters Derived by Ward's Method

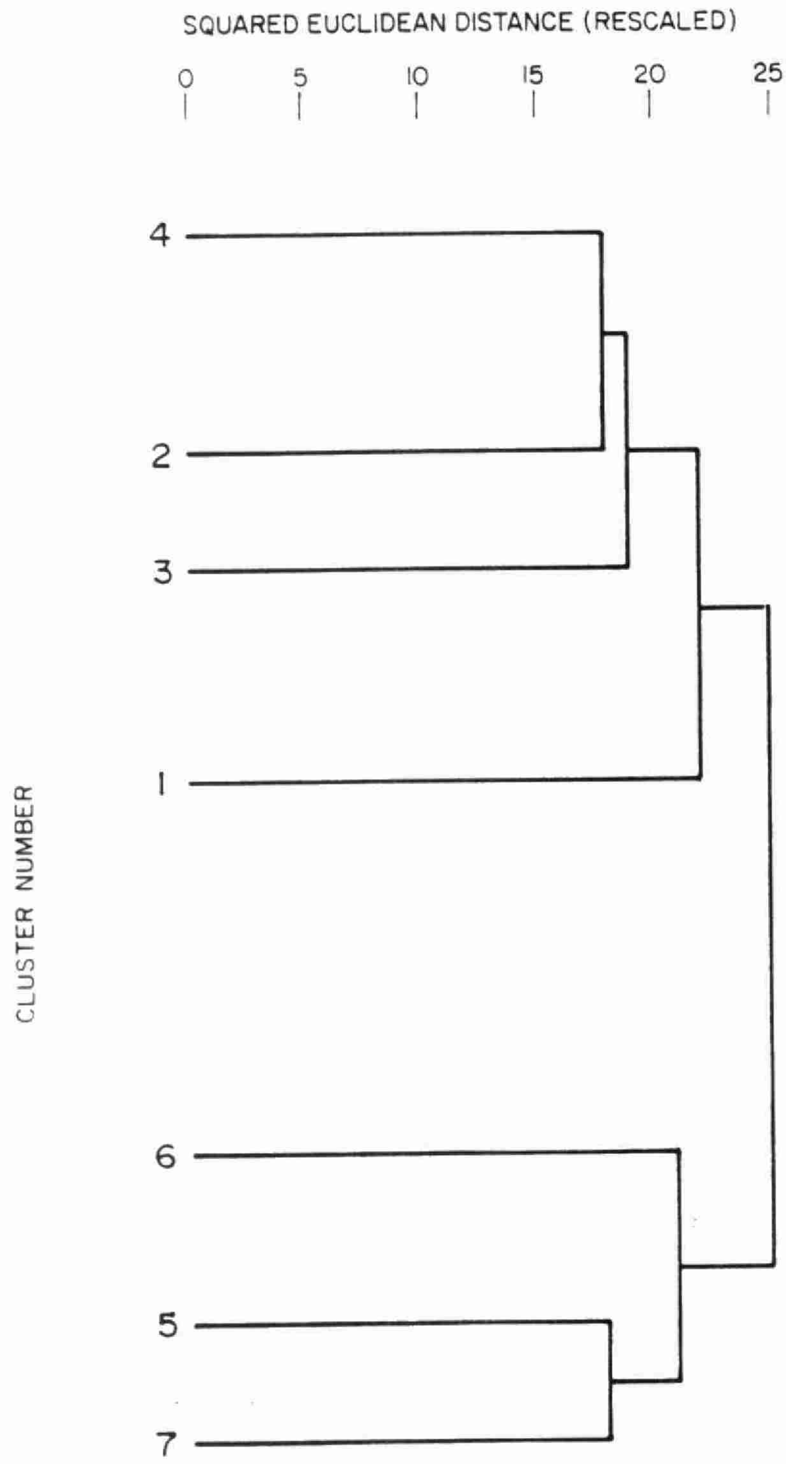

TABLE 3.1: CHARACTERISTICS OF BENTHIC COMMUNITY CLUSTERS IN THE ST. MARYS RIVER - 1985

Parameter	CLUSTER NUMBER 1	2	3	4	5	6	7
COMMON TAXA	Immat. Tubificids w/o chaetae *Nematoda Procladius Bezzia *Manayunkia Spirosperma	*Immat. Tubificids w/o chaetae *Nematoda *Manayunkia Nemertea Stylodrilus Pisidium Spirosperma Immature Tubificids with chaetae	*Immat. Tubificids w/o chaetae *Nematoda Nais variabilis	*Immat. Tubificids w/o chaetae *Nematoda *Chironomidae	Immat. Tubificids w/o chaetae *Nematoda Procladius Cricotopus Bezzia	Immat. Tubificids w/o chaetae * Nematoda Manayunkia Pisidium Amnicola limosa Valvata sincera Procladius Polypedilum *Chironomidae	Immat. Tubificids w/o chaetae *Nematoda Helisoma Procladius Chironomus Polypedilum Hyallela Hydracarina *Chironomidae
MEAN NO.TAXA	27	23	15	12	39	40	32
MEAN TOTAL DENSITY (No/m^2)	128,000	192,000	259,000	71,000	56,000	165,000	201,000
SUBSTRATE	Brown Silt Over Sand/Clay	Coarse Sand w or w/o Silt	Organic Silt	Silt	Variable Silty-Coarse Sand	Silt Over Sand	Brown Silt Over Sand/Clay
WATER DEPTH (m)	2-13.7	2.5-14	1-16	1.5-8.5	1-5.5	1.5-10.5	3-12
MACROPHYTES	Variable	Absent or Sparse	Variable	Usually Absent	Variable	Present	Usually Present
VISIBLE OIL	Absent-Slight	Absent-Very Strong	Slight-Very Strong	Absent-Very Strong	Absent-Slight	Absent-Slight	Absent-Very Strong
CURRENT	Usually None	Slight-Moderate	None	None-Strong	None-Moderate	None-Slight	None-Slight

* Dominant taxa

relatively low, while the mean total density was relatively high (192,000 organisms/m^2) in comparison with the apparently unimpacted group of station clusters (Nos. 1, 5, 6 and 7). Most of the common species among Cluster 2 stations were indicative of mesotrophic conditions, with more sensitive groups such as gastropods, isopods, ephemeropterans and trichopterans either substantially reduced in density or absent. On the basis of the relatively low numbers of taxa and high total densities relative to control areas upstream of Sault Ste. Marie and along the U.S. shoreline, stations included in Cluster 2 were considered to be slightly impaired in terms of pollution status.

Cluster 3

Stations included in Cluster 3 were situated near the Canadian shore of the St. Marys River, downstream of the main industrial outfalls (SMD 1.2-840, SMD 2.6-950); downstream of the eastern STP (SMD 5.0E-370 and -640); in Little Lake George (86, 87, 88); and in Lake George (100 and 102). All of these stations were depositional areas characterized by a silt substrate, no obvious current and the presence of an oily sheen on the sediment surface. This oily sheen ranged from slight to heavy, with the heaviest accumulations noted at two stations downstream of the industrial discharge - SMD 1.2-840 and SMD 2.6-950 (based on interpretation in the field). Macrophytes (Potamogeton sp. and Elodea) were present at these two stations and Stations 87 and 88 in Little Lake George.

Characteristic organisms at Cluster 3 stations consisted of nematodes, immature tubificids without capilliform chaetae (likely Limnodrilus spp.) and the naidid oligochaete Nais variabilis. Other frequently abundant taxa at these stations included the tubificids Q. multisetosus, I. templetoni and/or T. tubifex (both including immatures with capilliform chaetae), and chironomid species such as Chironomus sp., Dicrotendipes, Polypedilum, Cricotopus, Procladius and Ablabesmyia. The snail Helisoma sp. was also frequently present. All of these species (except Nais) have been identified as tolerant of severe organic enrichment. In addition, the relative abundance of the tubificid fraction was substantially greater than observed at Cluster 2 stations. The presence of nematodes suggests, however, that the conditions were not as impaired as those in Toronto Harbour where nematodes were reported as nearly absent in 1977 (Golini, 1979). The largest Nais variabilis populations were generally associated with areas supporting macrophyte growth. Of particular note was the low density or absence of the

polychaete M. speciosa at Cluster 3 stations, in contrast to its abundance at stations in the closely related Cluster 2 (Figure 3.1). The absence of M. speciosa suggests greater impairment of water and sediment quality than occurred at stations in Cluster 2. This greater degree of impairment is reflected in a much lower mean number of taxa (15) relative to Cluster 2 and a much greater mean total density (259,000 organisms/m^2). Both of these features are typical of organic enrichment. On this basis, as well as the species assemblage, Cluster 3 stations were considered moderately impaired.

Cluster 4

Cluster 4 included eight stations in the immediate vicinity of the Algoma Steel slip (SMU 1.0-2130, SMU 0.5-300, Stations 115, 116, 117, 118, 119 and 127), two stations near the Canadian shore below the rapids (SMD 0.8-600 and Station 107) and one station immediately downstream of the eastern STP (SMD 5.0E-520). Physical environmental conditions described at stations within this cluster group were variable. Substrate conditions varied from silt (SMD 5.0E-520) to hard pack clay (Station 116), with water depth ranging from 1.5 to 8.5 m. There were generally no macrophytes, and the presence of an oily sheen varied from absent to heavy. Current conditions were also variable, with descriptions ranging from no obvious current to strong current.

The cluster was defined biologically by the presence of immature tubificids without capilliform chaetae (likely Limnodrilus spp.). Nematodes were also present at a majority of stations. Other common species included the tubificid Q. multisetosus and the chironomids Procladius and Cryptochironomus. Few other taxa were common at these stations. All of the species described above are tolerant of organic pollution. The mean number of taxa per station in Cluster 4 was only 12 (the lowest of all clusters), with a mean total density of 71,000 organisms/m^2. The variation in total densities at stations within Cluster 4 is very large, with very high densities occurring at organically enriched areas, and very low densities at some locations where effluent discharges may be exerting a toxic effect. For example, the mean total density of organisms at Station 116 in the Algoma slip was only 88/m^2, suggesting a toxic inhibition of benthic community development, perhaps in combination with poor habitat conditions (the substrate was a rather hard, uniform clay with very little overlying silt). At Station SMD 5.0E-520 near the STP, severe organic enrichment is implied by the extremely high mean total density of 345,000/m^2. One feature common to all stations, however, is a low number of taxa

relative to stations in all other clusters, and a general predominance of pollution-tolerant forms.

Biologically unusual stations within Cluster 4 included Stations 127 and SMD 0.8-600. At Station 127 in the presence of a silt substrate, nematode densities reached 220,000 organisms/m^2 or 70% of the population. The remainder consisted primarily of L. hoffmeisteri (including immatures) and Q. multisetosus. At Station SMD 0.8-600, coelenterates (Hydra sp.) accounted for 51% of the population, with the nemertean Prostoma rubrum and the oligochaete family Enchytraeidae accounting for the majority of the remainder. Both of these stations are near effluent discharge sources, and the biological assemblages probably reflect the influence of these sources. Unfortunately, information on the pollution tolerances or indicator value of most of these organisms is scant.

Clusters 1, 5, 6, and 7

The remaining four clusters (1, 5, 6 and 7) included stations which were either upstream of the discharges, near the U.S. shore or too far downstream to be substantially affected. As such, they were characterized by benthic associations which were low in tubificid oligochaetes and are considered to be relatively unimpaired.

Cluster 1

Cluster 1 included the majority (14 of 22) of stations located in Lake George. Other stations in this cluster included one at SMD 5.0E-60 and Station 85 in Little Lake George. All of these stations were characterized by a brown silt substrate with either sand or clay underneath. Depth was variable, ranging from 2 to 14 m, and current was generally non-existent, with three exceptions where there was a slight current present. The presence of macrophytes was variable, while oil tended to be visibly absent or present only in trace amounts.

Stations in Cluster 1 were characterized by five primary taxa, which included nematodes, polychaetes (M. speciosa), immature tubificids without capilliform chaetae (likely Limnodrilus spp.), the chironomid Procladius and the ceratopogonid Bezzia. Other species common to the majority of the stations in this cluster were the pea clam

Pisidium spp., the tubificid S. ferox, immature tubificids with capilliform chaetae (likely T. tubifex and/or I. templetoni) and the chironomids Cryptochironomus and Cryptotendipes.

The mean number of taxa per station in Cluster 1 was 27 (range 12 to 39), with a mean total density of 128,000 organisms/m^2. High organism densities and the presence of non-tolerant organisms at most of the stations within the cluster, suggest that the region including Cluster 1 stations was generally unimpaired overall, with some degree of organic enrichment. Variation within the cluster does exist, however, with stations at the north end of Lake George (Stations 96, 97, 98, 104, 105 and 106) tending toward moderate impairment, displaying unusually high densities of either nematodes or polychaetes and having an oily sheen on the surface of the substrate. This area likely represents a depositional zone from the St. Marys River inflow.

Cluster 5

Stations included in Cluster 5 were situated downstream of Whitefish Bay (Station 126), 2.5 km above the St. Marys falls (Stations SMU 2.5-1830, -1300 and 123, 124) on the Canadian shore upstream of the Algoma slip (Station 121), opposite the Algoma slip (SMU 0.5-200), and on the northeast side of Lake George (Station 99). Station characteristics were variable for all recorded parameters. Substrates ranged from silty-sand to coarse sand with a relatively shallow water depth range of 1 to 5.5 m. Visible oil was generally absent or at the most slight, and macrophytes were present or absent. Perceived current was absent in most cases, with only Station 121 and SMD 0.5-200 having a moderate current.

Characteristic taxa were Nematoda, immature Tubificidae (without capilliform chaetae), the ceratopogonid Bezzia and the chironomids Procladius and Cricotopus. Other frequently occurring taxa included non-tolerant forms such as the ephemeropterans Hexagenia, Ephemera, Paraleptophlebia, Caenis and Stenonema; trichopterans such as Molanna and the snail Valvata. Tubificids tended to be a minor portion of this community, with chironomids forming the majority of the assemblage. While most of these tended to be recognized as facultative forms (i.e., Procladius and Cricotopus), the high mean number of taxa (39), the low mean total density (56,000/m^2), and the location of these stations either upstream or well downstream of known point sources in the river suggest that this population is representative of a relatively unimpaired community.

Cluster 6

Cluster 6 was the second largest cluster (after Cluster 1), including 14 stations. These stations were located in Leigh Bay (SMU 2.5-2470), near the U.S. shore below the St. Marys Falls (SMD 1.2-15 and SMD 2.6-40), in Lake Nicolette (Stations 108, 109, 110, 111, 112 and 114) and in Lake George (Stations 83, 90, 91, 94 and 103). Characteristics of these locations were a substrate community of silt over sand, a water depth ranging from 1.5 to 10.5 m, a local macrophyte community (Chara, Potamegeton, Elodea and Isoetes), an absence or very slight trace of oil on the substrate surface, and generally no current, indicating potential depositional areas. Essentially all locations were either upstream or across the river from point sources, or were well removed downstream (Lake George).

Characteristic taxa included the ubiquitous nematodes and immature tubificids (without capilliform chaetae), the chironomids Procladius and Polypedilum, the polychaete M. speciosa, pea clams, and the snails V. sincera and Amnicola limosa. Other commonly occurring taxa included the isopods Asellus and Lirceus, the amphipod Hyalella azteca and the ephemeropterans Hexagenia and Ephemera. This assemblage is a mixture of facultative and non-tolerant organisms. The mean number of taxa at each station in this cluster was the highest of all seven at 40, with a mean total density of 165,000 organisms/m^2. As in Cluster 5, chironomid taxa dominated the benthic populations at the stations included in Cluster 6. This cluster is represented in situations that may be classified as relatively unimpaired, based on the high number of taxa, the presence of intolerant forms, and remote location of these stations from point sources of pollution.

Cluster 7

Cluster 7 is the smallest of all the clusters, and included only five stations. These were located upstream of the St. Marys Falls (Station 122, 125 and SMU 1.8-1690), downstream of the eastern STP (SMD 6.4E-280), and in Little Lake George (Station 89). Stations in this cluster were characterized by a brown silt over sand/clay substrate, water depths of 3 to 12 m, a general presence of macrophytes and very little if any perceptible current. Visible oil on the substrate surface was variable, and ranged from none to very abundant (SMD 6.4E-280).

Taxa common to all stations included nematodes, immature tubificids (without capilliform chaetae), the chironomids Chironomus, Procladius and Polypedilum, Hydracarina (water mites), the amphipod H. azteca and the snail Helisoma. Other common taxa included the isopods Asellus and Lirceus and the chironomids Psectrocladius, Polypedilum, Ablabesmyia and Procladius. As noted before, most of these taxa are facultative or tolerant forms. However, the mean number of taxa within this cluster remains relatively high at 32, with a mean total density of 201,000 organisms/m^2, the majority of these being chironomids. Tubificids were found in relatively low densities. In general, stations within this cluster may be classified as unimpaired by virtue of the relatively high mean number of taxa. Exceptions include some stations identified as having a high oil content in the sediments, although these locations supported benthic faunas that were generally similar to those having lower oil levels within the same cluster.

3.4 Temporal Comparisons of Spatial Patterns

Results of the 1985 cluster analysis are summarized in Figure 3.2A and 3.2B in terms of the following pollution impairment zones:

1. severe:
   a) extreme tubificid dominance (i.e., L. hoffmeisteri and immatures without capilliform chaetae), tolerant chironomids, low numbers of taxa and high total densities, or
   b) communities with either very low total densities and low numbers of taxa, and/or high densities of nematodes with few other taxa (Station Cluster 4);
2. moderate: tubificid dominance with high densities of nematodes and facultative chironomids, absence of polychaete worms, reduced numbers of taxa and high total densities (Station Cluster 3);
3. slight: nematode and polychaete dominance with moderate densities of tubificids and some non-tolerant groups present (Station Cluster 2); and
4. unimpaired: communties tending towards chironomid dominance, with several non-tolerant groups (e.g., ephemeropterans and trichopterans) present, low tubificid densities and high numbers of taxa (Station Clusters 1, 5, 6 and 7).

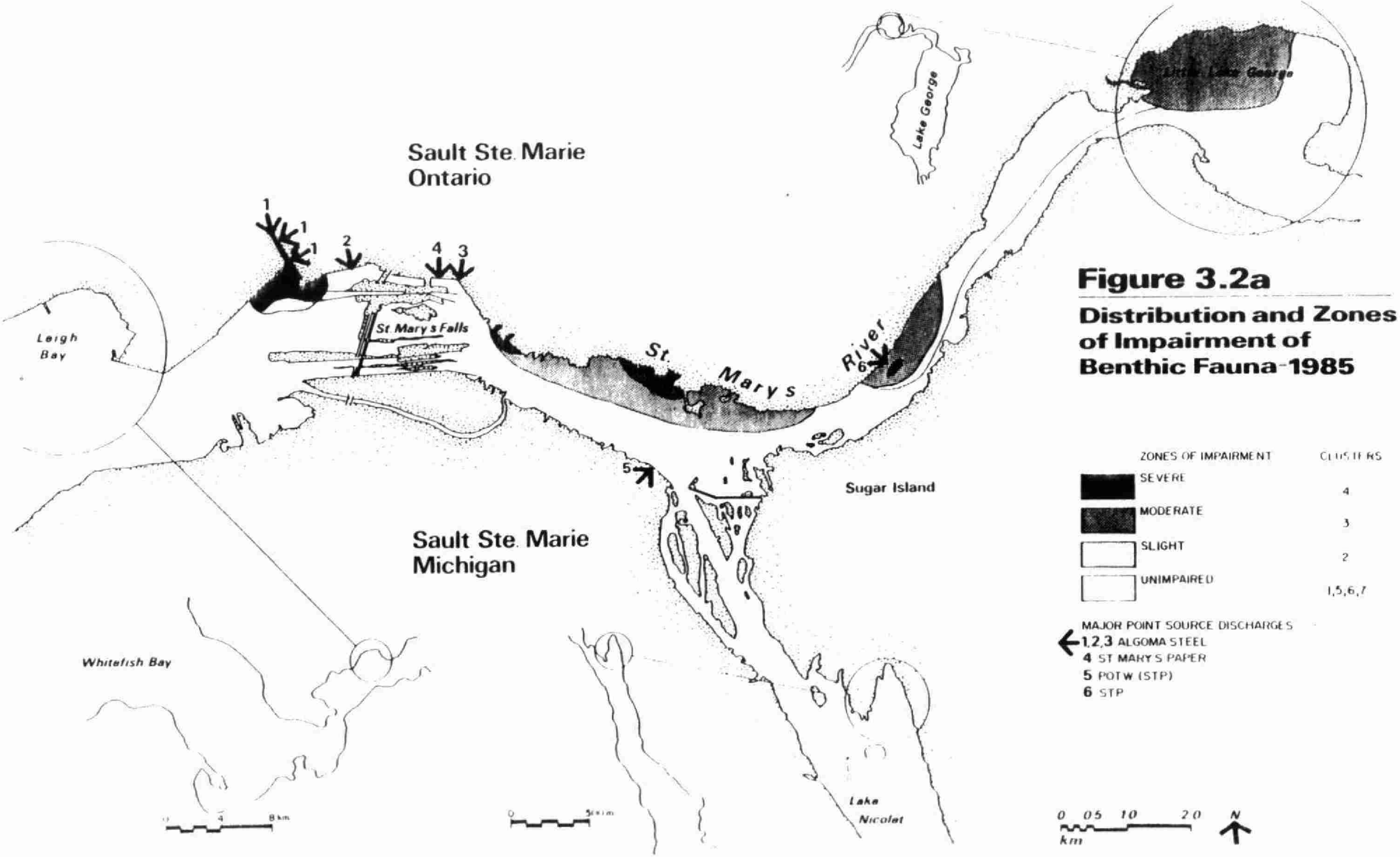

Figure 3.2a

Distribution and Zones of Impairment of Benthic Fauna-1985

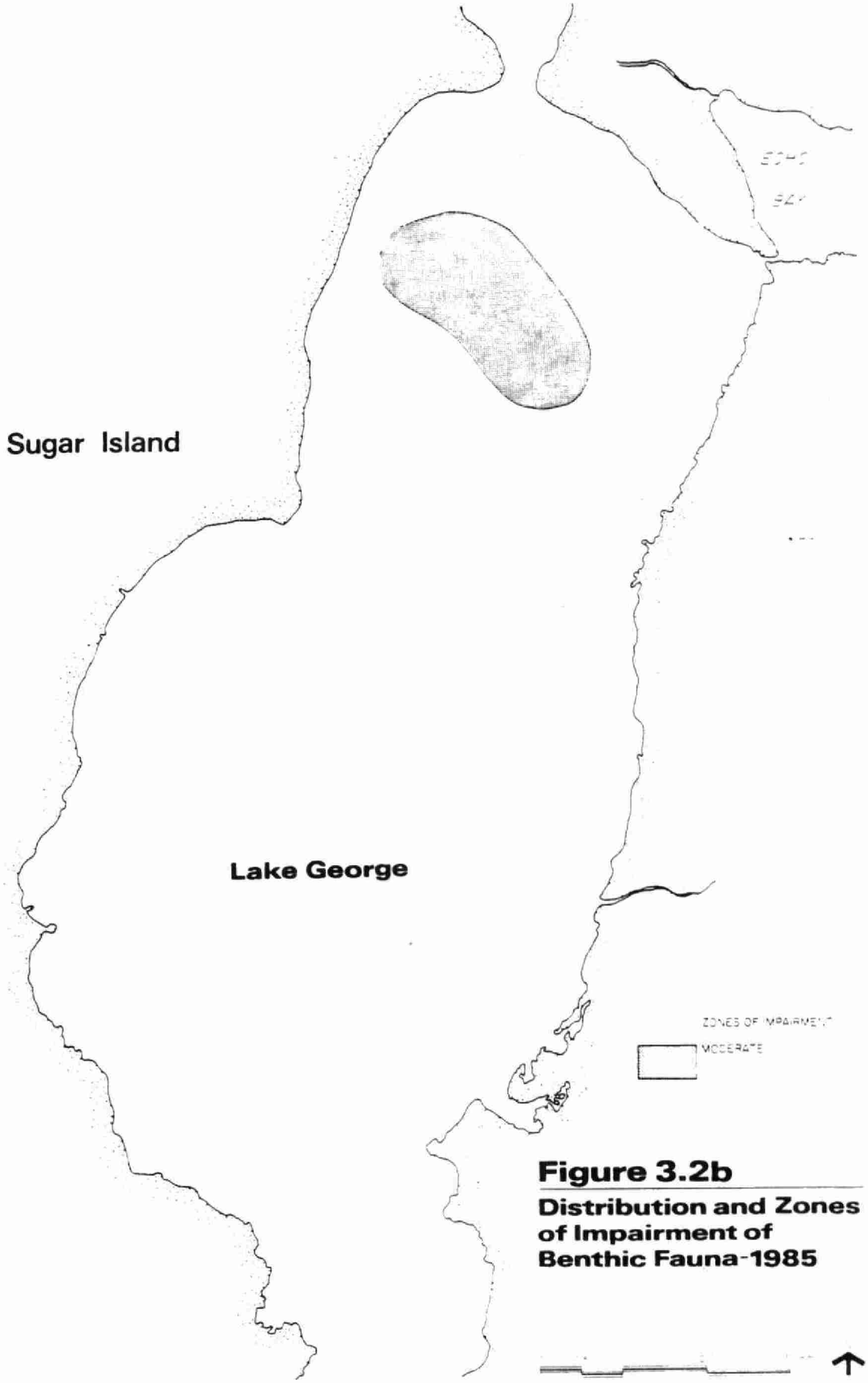

Figure 3.2b
Distribution and Zones of Impairment of Benthic Fauna-1985

The spatial distribution of these four zones, based on assignment of each cluster of stations to one of the zones, is used to infer any major changes in benthic community status between years.

In comparisons among surveys, methodological differences must be considered. As noted in Section 2, increased sorting efficiency (due in part to smaller mesh size and use of a microscope) contributed to higher total densities in 1985 than in earlier surveys. Total organism densities in 1985 ranged from 88 to 591,000 organisms/m^2, compared to a range of 104 to 40,000/m^2 in 1983, a difference of up to one order of magnitude.

In addition, principal components analysis (Section 2 and Appendix 2) suggested numerous faunal shifts between 1983 and 1985. Two particularly notable shifts involved nematodes and polychaetes which were rare or absent in all previous sureys, and abundant and often dominant in 1985. These organisms are small enough to be influenced by mesh size or sorting efficiency (Golini, 1979). Other small organisms, which occurred in higher densities in 1985, included naidid oligochaetes and early instar chironomids. However, other shifts such as the increased densities of Hexagenia, a comparatively large mayfly nymph, in 1985, were probably not related to mesh size or sorting technique.

Total organism densities reported at some locations in 1985 are very high (>100,000/m^2) and comparable to the maximum densities reported in the most heavily polluted harbours of the Great Lakes (Cook and Johnson, 1974). These high densities can, to some extent, be accounted for by the large numbers of very small organisms retained by a 200 um mesh. In contrast, most benthic surveys of the Great Lakes have been carried out using a U.S. #30 (about 500 um) mesh, which would not retain as many organisms. Greater research into the environmental tolerances of many of these small but abundant taxa (nematodes, naidids) would facilitate interpretation of their significance in benthic communities and pollution surveys.

In spite of the differences between surveys, inferred zones of impairment in 1985 were similar to those reported in 1983 (Figure A1.3). Both surveys indicated a zone of severe impairment below the St. Marys Falls near the Canadian shore at SMD 0.8. In 1985, however, this zone did not include SMD 1.2-840, suggesting some improvement here since 1983. This change was primarily due to the presence in large numbers of the nemertean,

Prostoma rubrum, which is typically found in well-oxygenated, littoral standing water and cannot tolerate low oxygen conditions (Pennak, 1978).

The 1985 survey indicated severe impairment, possibly resulting from toxicity, in the vicinity of the Algoma slip. In 1983, this area was identified as moderately impaired, based on 3 stations located outside the slip. The greater number of stations in closer proximity to the slip probably accounts for the change in status of this area in 1985 relative to 1983. Species assemblages at the stations common to both surveys had not changed markedly.

Both surveys also suggested a zone of moderate impairment which extends downstream from St. Marys Falls, close to the Canadian shore, to the vicinity of SMD 2.6. Another zone of moderate impairment was associated with the easterly Sault Ste. Marie STP, extending to within 370m of the U.S. shore. Differences from the 1983 pattern included the identification of SMD 5.0E-520 and station 107 as severely impaired in 1985. Analysis of the detailed species lists from both years substantiates the differentiation of SMD 5.0E-520 from adjacent stations SMD 5.OE-640 and 370 on the basis of a more complete tubificid dominance (primarily L. hoffmeisteri) and only 3 other taxa. The differentiation of station 107 from nearby stations was related to a lower total density and fewer taxa.

In 1985, a zone of slight impairment was evident within the Lake George Channel discharging into Lake George. In 1985, this zone extended from SMD 5.0E-210 downstream past transect SMD 6.4E (except SMD 6.4E-210 near the U.S. shore), into Little Lake George. In the early previous surveys (1968 and 1973), this section was designated as moderately impacted. The apparent improvement here is based on the presence of taxa such as S. heringianus, P. rubrum as well as on a slight increase in taxa and reduction in densities relative to the moderate zones. The absence of an impairment designation in this portion of Little Lake George in 1983 is attributed to the lack of sampling in this area during the 1983 survey. Another station described as slightly impacted in 1985 includes Station 120 just outside the severe impact zone near the Algoma slip.

A zone of moderate impairment at Stations 86, 87 and 88 was identified in 1985 but not 1983 when these locations were not sampled. Species assemblages were similar here to

those reported in 1973 and were characterized by high tubificid densities (primarily L. hoffmeisteri and low numbers of taxa). The extent of this zone is similar to that indicated in 1973 (Hamdy et al., 1978).

A zone of moderate impairment was also identified in Lake George, at the two deep water stations. The sampling in Lake George in 1985 was the first time the lake has been extensively sampled, apart from a study in 1975 by Hiltunen and Schloesser (1983).

Hiltunen and Schloesser (1983) related the distribution of the ephemeropteran Hexagenia to the presence or absence of visible oily residues in sediments in the St. Marys system downstream of the STP[1]. Substrates collected from Lake George in 1985 were contaminated by oily substances at most stations between the STP and upper Lake George, similar to the pattern indicated by Hiltunen and Schloesser. The 1985 results suggest that the extent of sediment contamination by oil in the Lake George Channel has not changed from that observed in 1975 (Figure 3.3). Oil was absent in the Lake Nicolet Channel in 1985, and was very limited in distribution in the more extensive study of this area in 1975 (Figure 3.3). The distribution of Hexagenia in 1985 has remained similar to that observed in 1975. In 1985, Hexagenia was absent from sediments in 27 of 32 stations analyzed in the St. Marys River, Lake Nicolet, Lake George Channel, Little Lake George and Lake George where even slight amounts of visible oil were present. In the remaining 19 stations where visible oil was absent, 16 had Hexagenia populations present (Figure 3.3). At two of the three remaining stations where Hexagenia was absent, the bottom substrate was primarily sand which deters Hexagenia inhabitation (Edmunds, et al 1976). Where similar stations were sampled, densities of Hexagenia were usually higher in 1985 than in 1975 (Figure 3.3). Whether this difference represents a real temporal trend or is due to differences in sampling is not known.

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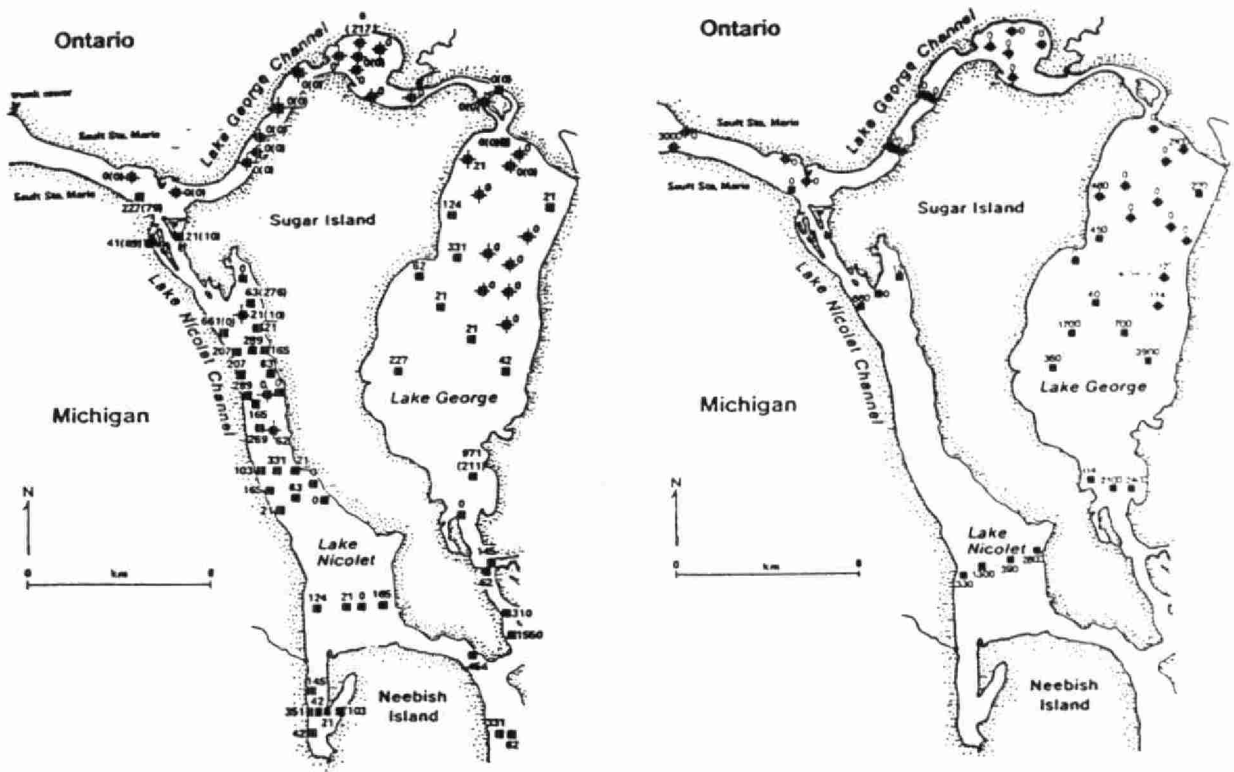
1 This does not imply that the STP is the source of the oil. Oil also occurred in abundance at stations upstream of the STP in 1985.

FIGURE 3.3 DISTRIBUTION ON HEXAGENIA NYMPHS AND VISIBLE OIL IN THE ST. MARYS RIVER SEDIMENTS IN 1975 AND 1985



1975 1985

(from Hiltunen and Schloesser, 1983)

■ - Sampling Location and Density (No/m^2) Of Hexagenia Nymphs

( ) - Indicates Densitites Collected By OWRC In 1967

+ - Indicates Presence Of Visible Oil In The Substrate

3.5 Sediment Quality Relationships of Benthic Communities

3.5.1 Distributions of Sediment Quality Variables

Prior to transformation, 29 of 33 sediment parameters were significantly skewed, 27 showed significant ($p < 0.05$) kurtosis, and none were normal in distribution. After transformation, 13 sediment parameters were still skewed, 15 showed kurtosis, and 18 were normal in distribution. In all cases, the selected transformation improved the distribution, by reducing the absolute magnitude of skewness and kurtosis measures (Appendix 5, Table A5.2).

It was not possible to normalize any of the pesticide parameters due to the large number of observations below the detection limit (these were all considered equal to the detection limit for statistical analysis). Similarly, pH was unlikely to be normalized due to the large number of missing observations replaced by the mean. Subsequent analyses were performed with and without the non-normal parameters; however, results based on the full data set were most interpretable, and these are presented in the following sections.

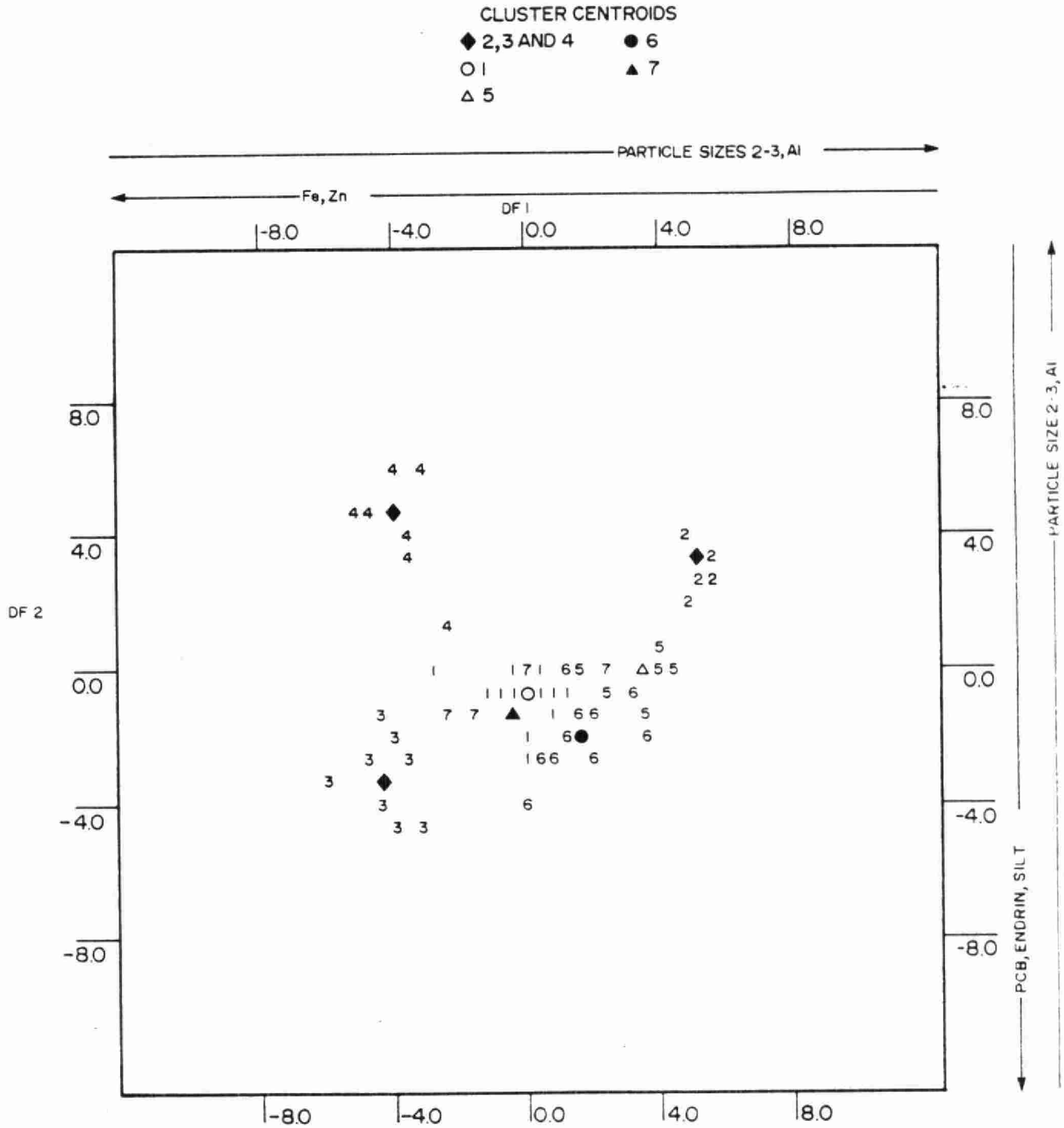
3.5.2 Discriminant Analysis

Figure 3.4 illustrates separation in discriminant space of the seven station groups defined by cluster analysis in Section 3.3. Stations in the same cluster (with the same numeric label in Figure 3.4) have similar overall species compositions. Clusters 2, 3 and 4 were considered to represent impacted groups, based on the recognized pollution tolerance of their characteristic species (Table 3.1, Section 3.3).

Station Clusters 3 and 4 are distinguished by high sediment concentrations of iron and zinc in relation to particle size (DF1 in Figure 3.4). Cluster 2 sediments are distinguished on the same discriminant function by a large fraction of particulate material (45 to 1,000 um), but lower concentrations of these metals. Relationships between bulk sediment chemistry as examined here, and benthic community response, are poorly understood, and may be strongly influenced by the fractions of sediment contaminants that are loosely associated with the sediment and therefore are more bioavailable. Nonetheless, geometric mean iron concentrations of 3.1% and 6.3% and zinc concentrations of 174 and 257 ug/g at stations defined by Clusters 3 and 4,

FIGURE 3.4

Station Clusters Plotted on First Two Discriminant Functions



respectively, are considerably higher than the MOE dredge disposal guidelines of 1% for iron and 100 ug/g for zinc (Persaud and Wilkens, 1976), indicating that these key elements in DF1 are relatively high in concentration at these impacted locations; thus their influence on cluster separation appears plausible. Cluster 3 sediments are distinguished from those of Cluster 4 by higher concentrations of PCB and less particulate material of size class 2 (DF2), in addition to their metal content. The first three discriminant functions were statistically significant ($p < 0.05$), with the first two collectively accounting for 72% of variance in cluster membership (Table 3.2).

Station Clusters 1, 5, 6 and 7 were not readily distinguishable from each other on the basis of the first two discriminant functions, but were reasonably well distinguished as a group from each of the three impacted station clusters. With the other functions, primarily DF3 (a particle size gradient), some discrimination within this group was achieved. Cluster 1 had the most fine material (< 45 um), while Cluster 5 had the least. Three stations within this four-cluster group were misclassified by the full set of discriminant functions (i.e., predicted on the basis of sediment characteristics to be in the wrong cluster). The overall percentage of stations correctly classified was 95.7% (Table 3.3).

Standardized discriminant function coefficients are tabulated in Appendix 6, Table A6.1. Sediment variables with coefficients greater than 1.9 in absolute value are listed on the DF1 and DF2 axes of Figure 3.4. Means for these variables in each station cluster (after transformation) are shown in Table 3.4. Discriminant function scores for each station are tabulated in Appendix 6, Table A6.2.

It was not possible to perform Box's test of multivariate homogeneity of variance with this analysis, because there were too few stations in each cluster in relation to the number of sediment variables. This results in non-singular group covariance matrices which the test cannot accommodate.

Varimax rotation of the discriminant functions was attempted (Kaiser, 1958). However, the unrotated solution was more interpretable. Green (1979) notes that this is often the case in ecological applications. The rotated solution is not presented.

TABLE 3.2: SIGNIFICANCE OF DISCRIMINANT FUNCTIONS OF SEDIMENT CHARACTERISTICS

Function	Eigen-value	Percent of Variance	Cumulative Percent	Significance After Removal		
				Chi-squared	df	p
1	10.48398	43.10	43.10	278.04	170	0.0000
2	7.12867	29.30	72.40	177.46	132	0.0051
3	2.87730	11.83	84.23	112.42	96	0.1209
4	1.90372	7.83	92.06	61.25	62	0.5031
5	1.49856	6.16	98.22	17.23	30	0.9689
6	0.43375	1.78	100.00	-	-	-

Standardized discriminant function coefficients for each sediment variable, and discriminant scores on each function for each station, are listed in Appendix 6.

TABLE 3.3: PREDICTION OF STATION CLUSTER MEMBERSHIP FROM DISCRIMINANT FUNCTIONS OF SEDIMENT CHARACTERISTICS

Actual Cluster	No. of Stations	Predicted Cluster Membership 1	2	3	4	5	6	7	Percent Correct
1	16	15	-	-	-	-	1	-	93.8
2	7	-	7	-	-	-	-	-	100.0
3	9	-	-	9	-	-	-	-	100.0
4	11	-	-	-	11	-	-	-	100.0
5	8	-	-	-	-	8	-	-	100.0
6	14	-	-	-	-	-	13	1	92.9
7	5	-	-	-	-	1	-	4	80.0
TOTAL	70								95.7

TABLE 3.4: STATION CLUSTER MEANS OF SELECTED[1] SEDIMENT CHARACTERISTICS

Sediment Variable[1]	Cluster:	Station Cluster Mean (after transformation)[2]						
		1	2	3	4	5	6	7
Iron		4.38	3.90	4.49	4.80	3.96	3.91	4.35
Zinc		2.09	1.48	2.24	2.41	1.35	1.47	1.99
Size 2 (45-1,000 um)		0.66	1.23	0.71	0.93	1.15	1.07	0.76
Size 3 (< 45 um)		0.91	0.30	0.85	0.60	0.36	0.49	0.80
Aluminum		4.06	3.48	3.96	3.89	3.57	3.64	3.94
PCBs		1.33	1.30	1.57	1.40	1.30	1.38	1.36
Endosulphan II		0.61	0.60	0.65	0.77	0.60	0.60	0.60
Silt		0.92	0.32	0.87	0.52	0.43	0.57	0.85

[1] Sediment variables shown are the main contributors to discriminant functions 1 and 2, with standardized DF coefficients exceeding 1.9 in absolute value.

[2] See Table A5.2 for original units and transformation.

A stepwise discriminant analysis was also performed, using four groups of stations (Clusters 1, 5, 6 and 7 combined). In this analysis, a sediment variable is removed from the predictor set (if it ceases to make a significant contribution), or added to the predictor set (if it significantly increases discrimination between groups) at each step. Green (1979) recommends against the stepwise approach, since the discriminant functions rather than the original variables are assumed to be controlling species distribution; however, it is one way of reducing the number of original variables to the point that Box's test can be performed. The stepwise solution is illustrated in Appendix 6, Figure A6.1.

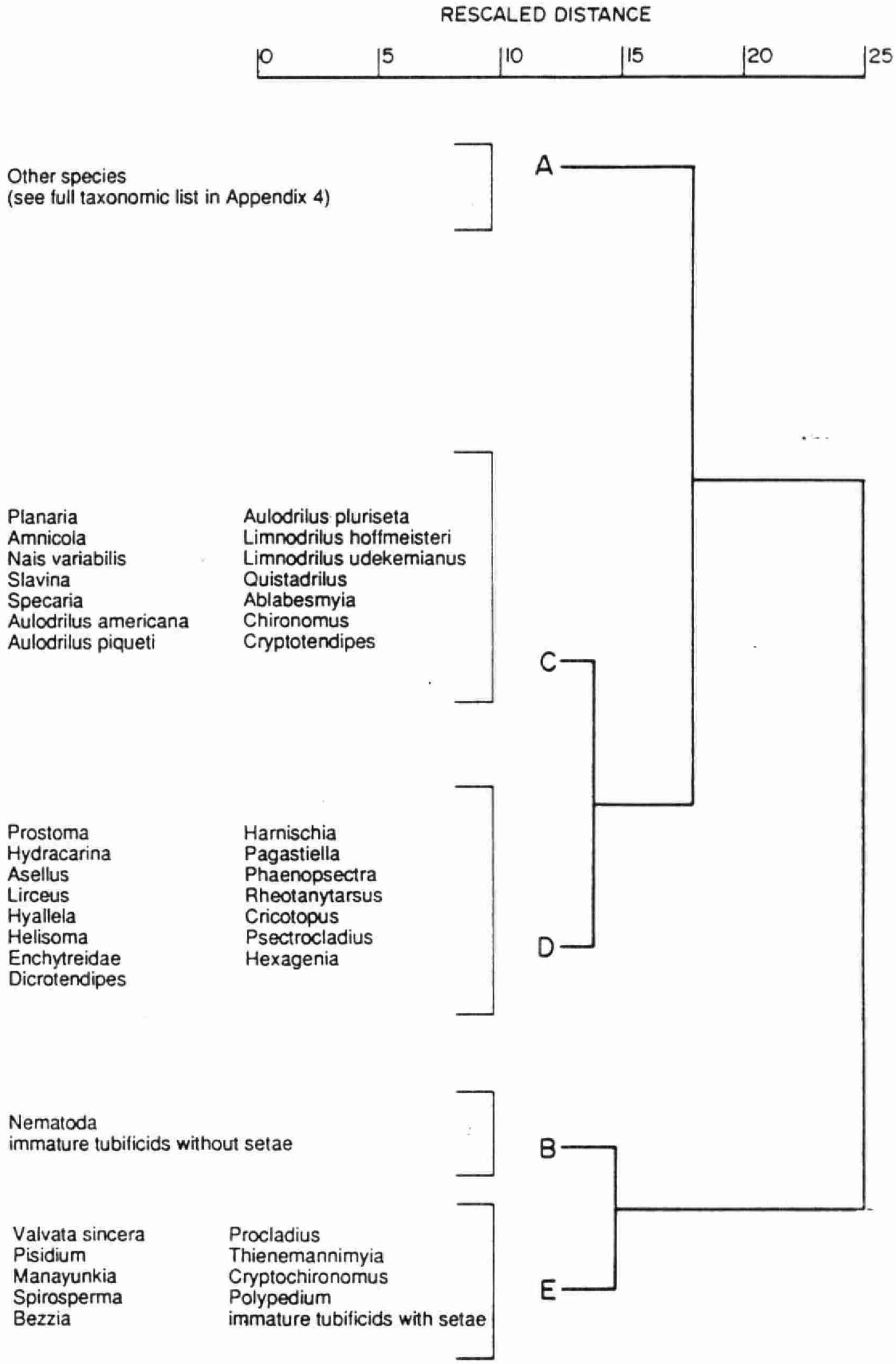
3.5.3 Community Index Analysis

Benthic species clusters, or guilds, based on R-mode cluster analysis, are illustrated in Figure 3.5. Similarities between guilds with respect to their spatial distributions are indicated by the rescaled distance values at which they combine. Distance is an inverse measure of similarity. Five guilds are evident at an interpretation level of 13.5 on the distance scale. These are labelled A to E on the dendrogram.

Guilds B and C are comprised primarily of pollution tolerant taxa (Figure 3.5). Guild B consists of Nematoda and immature Tubificidae without hair setae. The immatures are most likely L. hoffmeisteri based on the relative abundance of adults. Station clusters 2, 3 and 4 were all characterized by dominance of Guild B taxa, and were identified as pollution-impacted (Section 3.3). Guild C includes both pollution-tolerant species, such as Limnodrilus spp., Q. multisetosus and Chironomus, and some species that are less tolerant of organic pollution, such as Aulodrilus spp., suggesting that Guild C occurs in areas that are less impaired than areas inhabited by Guild B.

Species Guilds D and E are described by some relatively intolerant and mesotrophic taxa, such as Hexagenia (Guild D) and Polypedilum (Guild E), with relatively few eutrophic indicators. Guild D is probably more indicative of unimpacted conditions than is Guild E, based on the occurrence of the intolerant Hexagenia in the former, and greater representation of forms tolerant of organic enrichment in the latter (e.g., Tubificidae, Procladius, Manayunkia). High index values for these guilds, particularly for Guild D, tend to occur at stations assigned to Station Clusters 1, 5, 6 and 7, which are described as relatively unimpaired (Section 3.3).

FIGURE 3.5 Species Clusters (Guilds) Based on Concordance of Spatial Distributions



Species Guild A includes a very large number of species (>100), most of which tend to be uncommon at most locations. Because most of the dominant forms and many of the key indicator species occurred in Guilds B to E, interpretation of the pollution indicator value of Guild A was not attempted.

The community indexes representing dominance of each Guild B, C, D and E were examined for correlation with sediment characteristics. Indexes for each station are listed in Appendix 6, Table A6.3. Coefficients of correlation between dominance indexes and sediment parameters are listed in Table 3.5.

Guild B and Guild C dominance indexes were each positively correlated with various heavy metals, solvent extractables and TOC ($p < 0.01$). Guild B dominance was also positively correlated with several pesticides, while Guild C dominance was also correlated with fine particulates, phosphorus, LOI and TKN. Guild B dominance was negatively correlated with Eh, indicating association with reducing environments. These correlations support the contention that dominance by Guilds B and C is representative of impaired conditions.

Guild E dominance was positively correlated only with depth ($p < 0.01$), and negatively correlated only with ppDDE, suggesting that these taxa are not strongly indicative of pollution status. Guild D dominance was negatively associated with various heavy metals, endrin, solvent extractables, phosphorus, LOI, TOC and TKN. Thus, this group represents a relatively clean-water faunal assemblage, both on the basis of biological indicators and negative correlations with sediment-associated contaminants and organic matter.

Based on correlations with sediment characteristics, Guild B dominance appears to be the best general indicator of toxic contaminants (both metals and pesticides). This guild is also defined by two of the most abundant indicator taxa (Nematoda and Limnodrilus spp.), thus facilitating further interpretation of spatial trends in environmental quality. This index was plotted on a map of the study area to illustrate associations with known point sources. Figure 3.6 shows the highest index values in the vicinity of the Algoma slip and the Sault Ste. Marie, Ontario STP. Values greater than 0.25 in these areas were considered indicative of severe impact. Zones of moderate impact (index 0.18 to 0.25) were also apparent in a depositional area downstream of St. Marys Falls on the Canadian

TABLE 3.5: CORRELATIONS OF GUILD DOMINANCE INDEXES WITH SEDIMENT CHARACTERISTICS

Sediment Variable	Guild:	Correlation Coefficient C	B	E	D
Water Depth		-0.0353	0.1052	0.3572*	-0.3148*
Aluminum		0.4105*	0.1489	0.1470	-0.3976*
Arsenic		0.1786	0.4349*	0.0442	-0.3459*
Cadmium		0.4153*	0.0164	0.1782	-0.2315
Cobalt		0.2419	-0.0832	0.0729	-0.1733
Chromium		0.4104*	0.2491	-0.0816	-0.3543*
Copper		0.4740*	0.3016*	-0.0059	-0.4349*
Iron		0.2189	0.4115*	0.0233	-0.4154*
Mercury		0.5089*	0.3946*	0.1442	-0.5114*
Manganese		0.0916	0.3284*	0.0507	-0.2278
Nickel		0.3443*	0.2517	-0.0334	-0.3348*
Lead		0.3660*	0.3763*	0.0863	-0.4392*
Selenium		0.5006*	0.2153	0.0430	-0.3899*
Zinc		0.3641*	0.4413*	0.1321	-0.4800*
Silt Fraction		0.4941*	-0.0212	0.0963	-0.1950
Clay Fraction		0.2536	0.1128	0.1272	-0.3189*
Silt + Clay		0.4627*	0.0075	0.1048	-0.2629
Coarse (> 1,000 um)		-0.2372	0.1407	-0.1760	0.0951
Medium (45-1,000 um)		-0.4136*	-0.0625	-0.1416	0.3108*
Fine (< 45 um)		0.4324*	0.0594	0.1459	-0.3082*
Dieldrin		0.1671	0.0492	-0.2389	0.0289
Methoxychlor		0.0786	0.5862*	-0.1085	-0.3805*
Eh		-0.2797	-0.3907*	-0.0001	0.2913
Endrin		-0.2382	0.4975*	-0.2562	-0.0060
Endosulphan II		0.0146	0.7105*	-0.1828	-0.3171*
Endosulphan I		0.1488	0.5714*	-0.1884	-0.3189*
Heptachlor Epoxide		-0.0628	0.6914*	-0.2753	-0.2024
PCB		0.2820	0.1240	-0.2842	-0.1055
ppDDE		0.3820*	0.1367	-0.3347*	-0.1156
Loss on Ignition (LOI)		0.4793*	0.2855	0.0098	-0.3815*
Solvent Extractables		0.5910*	0.3284*	-0.0380	-0.4236*
Total Organic Carbon (TOC)		0.3511*	0.5807*	-0.0831	-0.4336*
Total Kjeldahl Nitrogen (TKN)		0.5408*	0.0381	0.0193	-0.1888
pH		0.2294	0.0664	-0.2340	0.1266
Total Phosphorus		0.5311*	0.0668	0.1068	-0.3562*

* Indicates coefficients differ significantly from zero ($p < 0.01$).

shore, downstream of the Sault Ste. Marie, Ontario STP to Little Lake George, and in a deep water depositional area of Lake George near the inlet. Mean sediment characteristics associated with each zone are listed in Table 3.6.

Impact zones defined on the basis of Guild B dominance (Figure 3.6) closely resemble the zones previously defined in terms of station clusters 2, 3 and 4 (Figure 3.2, Section 3.3). However, they suggest a slightly greater degree and extent of impact in Little Lake George and Lake George than discerned by station cluster distributions.

The best multivariate equation for prediction of Guild B dominance from sediment characteristics includes significant ($p < 0.05$) positive contributions from mercury, heptachlor epoxide, clay and TOC (Table 3.7). High concentrations of these constituents tend to increase the predicted dominance index. The equation includes significant negative contributions from arsenic, chromium and LOI. The complete equation explains 72% of variation in the dominance index (adjusted $R^2 = 0.72$).

The sediment characteristics identified by the multiple regression analysis as the best quantitative predictors of Guild B dominance differ from those identified by discriminant analysis as the key contributors to qualitative discrimination between station clusters defined on the basis of overall species composition. This is not surprising in view of the different dependent variables involved (indicator species dominance vs. station cluster membership). Nevertheless, the concordance of impact zones derived from the dominance index and station cluster patterns strengthens the finding of continued existence of tolerant benthic communities downstream of the Algoma Steel, St. Marys Paper and Sault Ste. Marie STP discharges, extending downstream along the Canadian shoreline as far as upper Lake George.

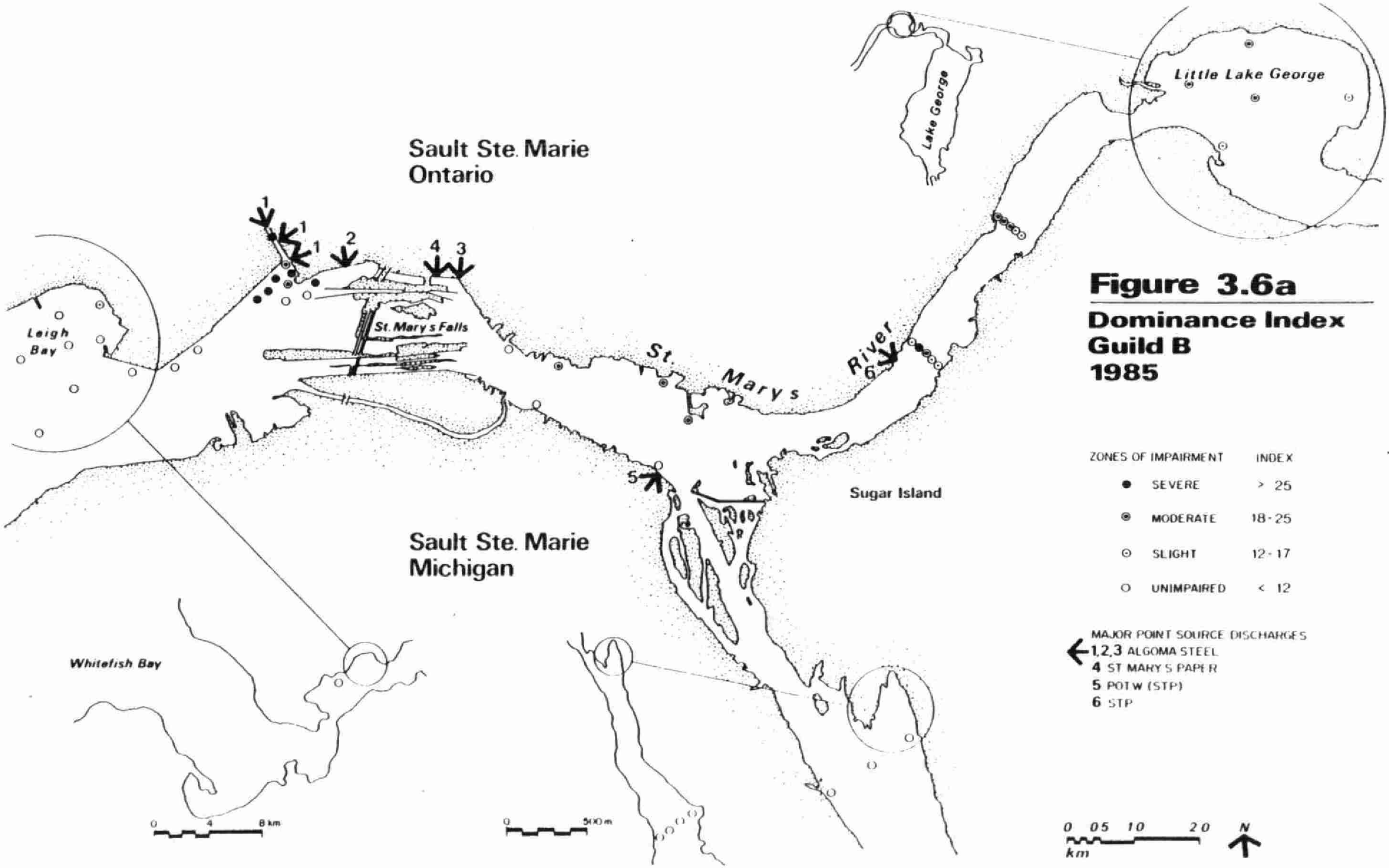


Figure 3.6a

Dominance Index Guild B 1985

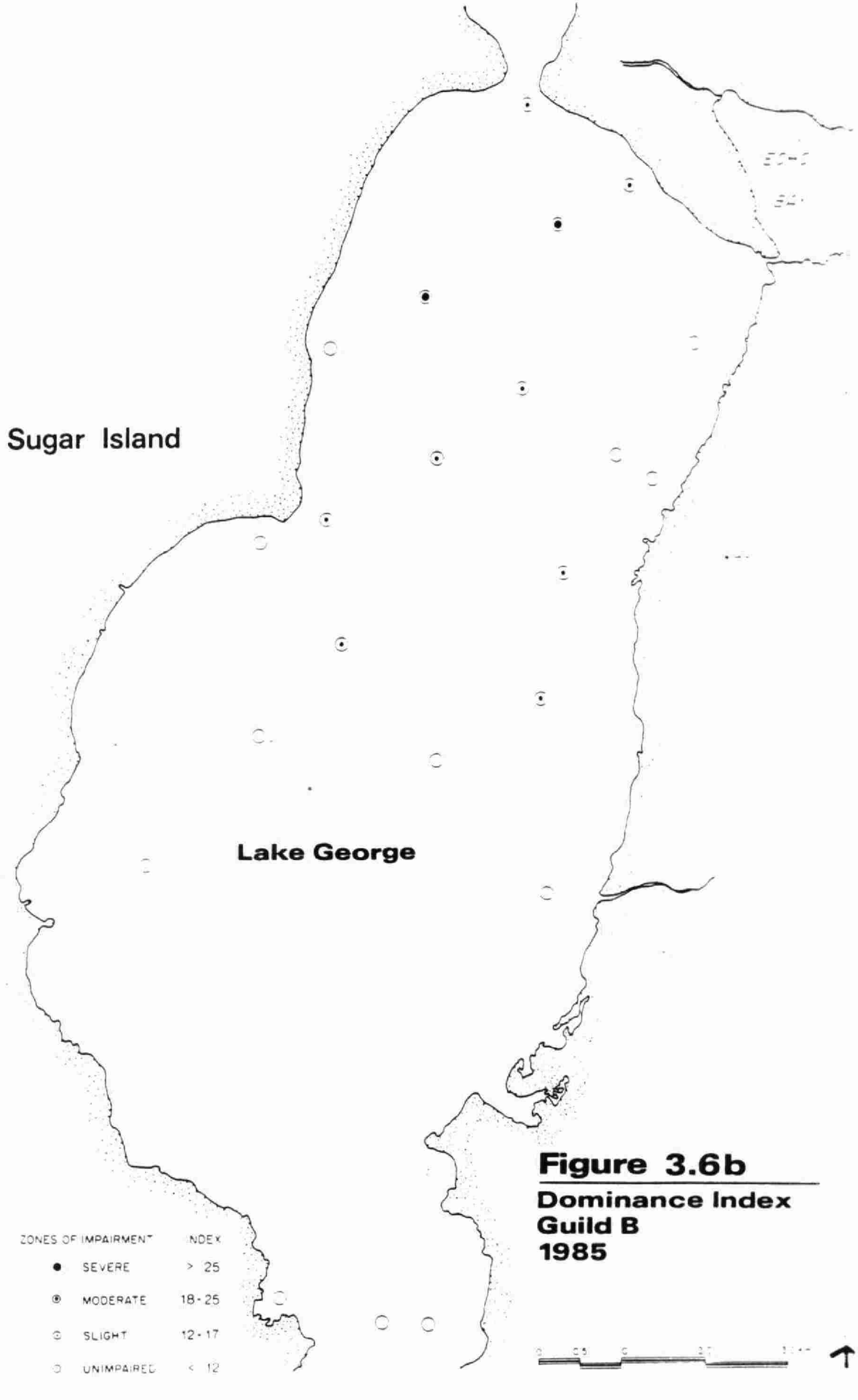


Figure 3.6b
Dominance Index
Guild B
1985

TABLE 3.6: MEAN SEDIMENT CHARACTERISTICS ASSOCIATED WITH GUILD B DOMINANCE CATEGORIES

Sediment Variable	Mean* Sediment Characteristic (after transformation)			
Index Range:	0.12	0.12-0.179	0.18-0.249	0.25
Water Depth	0.59	0.73	0.80	0.64
Aluminum	3.73	3.92	3.89	3.86
Arsenic	0.49	0.74	0.81	1.23
Cadmium	2.37	2.69	2.53	2.36
Cobalt	0.72	0.82	0.73	0.51
Chromium	1.34	1.49	1.60	1.61
Copper	1.15	1.44	1.48	1.53
Iron	4.08	4.32	4.41	4.78
Mercury	1.34	1.90	1.83	2.01
Manganese	2.32	2.43	2.52	3.04
Nickel	0.88	1.12	1.10	1.15
Lead	1.06	1.40	1.46	1.81
Selenium	2.39	2.94	2.77	2.81
Zinc	1.60	2.03	2.10	2.50
Silt	0.62	0.78	0.66	0.58
Clay	0.20	0.28	0.28	0.25
Silt + Clay	0.68	0.90	0.80	0.65
Coarse (> 1,000 um)	0.09	0.06	0.11	0.10
Medium (45-1,000 um)	1.00	0.77	0.82	0.98
Fine (< 45 um)	0.54	0.78	0.72	0.58
Dieldrin	0.88	0.69	1.03	0.74
Methoxychlor	0.61	0.64	0.74	1.20
Eh	478.56	457.94	407.25	262.43
Endrin	0.38	0.34	0.33	0.67
Endosulphan II	0.60	0.60	0.65	0.85
Endosulphan I	0.33	0.33	0.47	0.79
Heptachlor Epoxide	0.00	0.05	0.00	0.27
PCB	1.35	1.37	1.49	1.37
ppDDE	0.04	0.09	0.18	0.08
LOI	4.47	6.14	6.57	8.19
Sol. Extractables	2.70	3.16	3.16	3.26
Total Organic Carbon (TOC)	1.01	1.26	1.34	1.91
Total Kjeldahl Nitrogen (TKN)	2.74	2.96	2.82	2.74
pH	6.27	5.83	6.07	6.35
Total Phosphorus	2.52	2.65	2.64	2.56

* See Table A5.2 for original units and transformation.

TABLE 3.7: PREDICTION OF GUILD B DOMINANCE INDEX FROM SEDIMENT CHARACTERISTICS

Sediment Variable	Standard Partial Regression Coefficient	Significance Level (p)
Phosphorus	-0.17744	0.4106
Coarse Particulates (> 1,000 um)	0.10461	0.2675
Eh	-0.14656	0.1421
Loss on Ignition (LOI)	-0.84502	0.0001
Clay Fraction	0.47426	0.0026
Total Kjeldahl Nitrogen (TKN)	-0.25474	0.0954
Heptachlor Epoxide	0.25372	0.0079
Arsenic	-0.62972	0.0196
Mercury	0.65302	0.0002
Chromium	-0.30818	0.0396
Zinc	-0.33140	0.1594
Copper	0.39308	0.0909
Total Organic Carbon (TOC)	1.18693	0.0000
Aluminum	-0.40969	0.0973
Iron	0.56982	0.0708

Source	df	Sum of Squares	Mean Square
Regression	14	0.89083	0.06363
Residual	55	0.25501	0.00464
F = 13.72			
R = 0.88		R^2 = 0.78	Adjusted R^2 = 0.72

4.0 CONCLUSIONS

The 1985 St. Marys River benthic survey results were not amenable to pooling with those of the 1983 survey. Total densities were found to be generally greater in 1985, moreso at some stations than others. Sorters and sorting methods were identified as significant contributing factors. Principal components analysis suggested that a faunal shift in species associations, either real or sorter-related, had also occurred between the two surveys.

As concluded in 1983, the tubificid community associated with outfall areas was still apparent. Nematodes also reached high densities in all but the most severely enriched locations. General reductions in pollutant loadings from the Algoma Steel terminal basin and the St. Marys Paper operations since 1973 appear to have contributed to minor community changes, but were not reflected in major improvements in the pollutional status of the benthic community.

Cluster analysis of sampling stations based on species composition in 1985 showed that benthic communities characterized by tolerant species occurred in areas downstream of discharges, and other communities characterized by intolerant species occured in areas remote from point source effects. Similar impact zones can be derived from a community index reflecting dominance of nematodes and immature tubificids without setae. Discriminant analysis identified a heavy metal-particle size gradient and a pesticide-particle size gradient in sediment quality, which together provide a basis for separation of impacted station clusters from each other and from unimpaired stations.

Impacted stations generally occurred downstream of the Algoma Steel, St. Marys Paper and the easterly Sault Ste. Marie sewage treatment plant (STP) discharges. Some recovery was apparent with increasing distance downstream from the discharges; however, complete recovery was not apparent until the lower section of Lake George. The combined impact of effluents from all sources was still evident in Lake George, some 24 km downstream from the Algoma and St. Marys Paper discharges. In general, impacted locations were restricted to the Canadian portion of the St. Marys River, with a clean water fauna characterizing the relatively unindustrialized U.S. shore and all portions of the river upstream of pollution sources.

The distribution of Hexagenia nymphs was found to be associated with the occurrence of visible oil in the substrate of the St. Marys River, Lake Nicolet, and the Lake George Channel downstream to the outflow of Lake George. Generally, absence or low densities of nymphs coincided with the presence of oil in the sediments. The pattern observed in 1985 for the distribution of oil and Hexagenia was similar to that reported in 1975, which indicated the occurrence of oil as far downstream as the upper half of Lake George.

5.0 ACKNOWLEDGEMENTS

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APPENDIX 1

Historical Assessments of the St. Marys River Benthic Community and Algoma Steel Terminal Basin Effluent

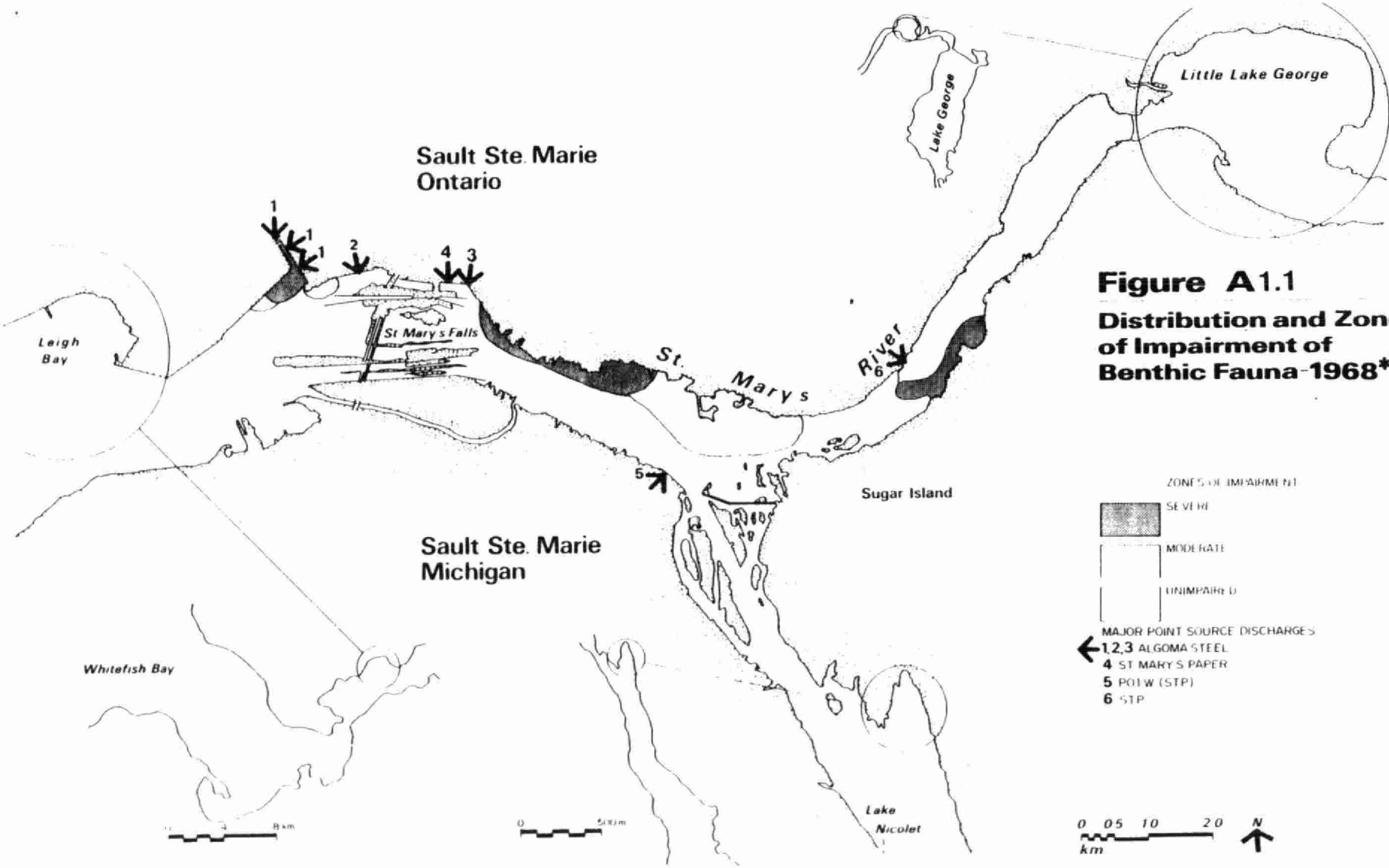


Figure A1.1
Distribution and Zones of Impairment of Benthic Fauna-1968*

*(McKee et al. 1984)

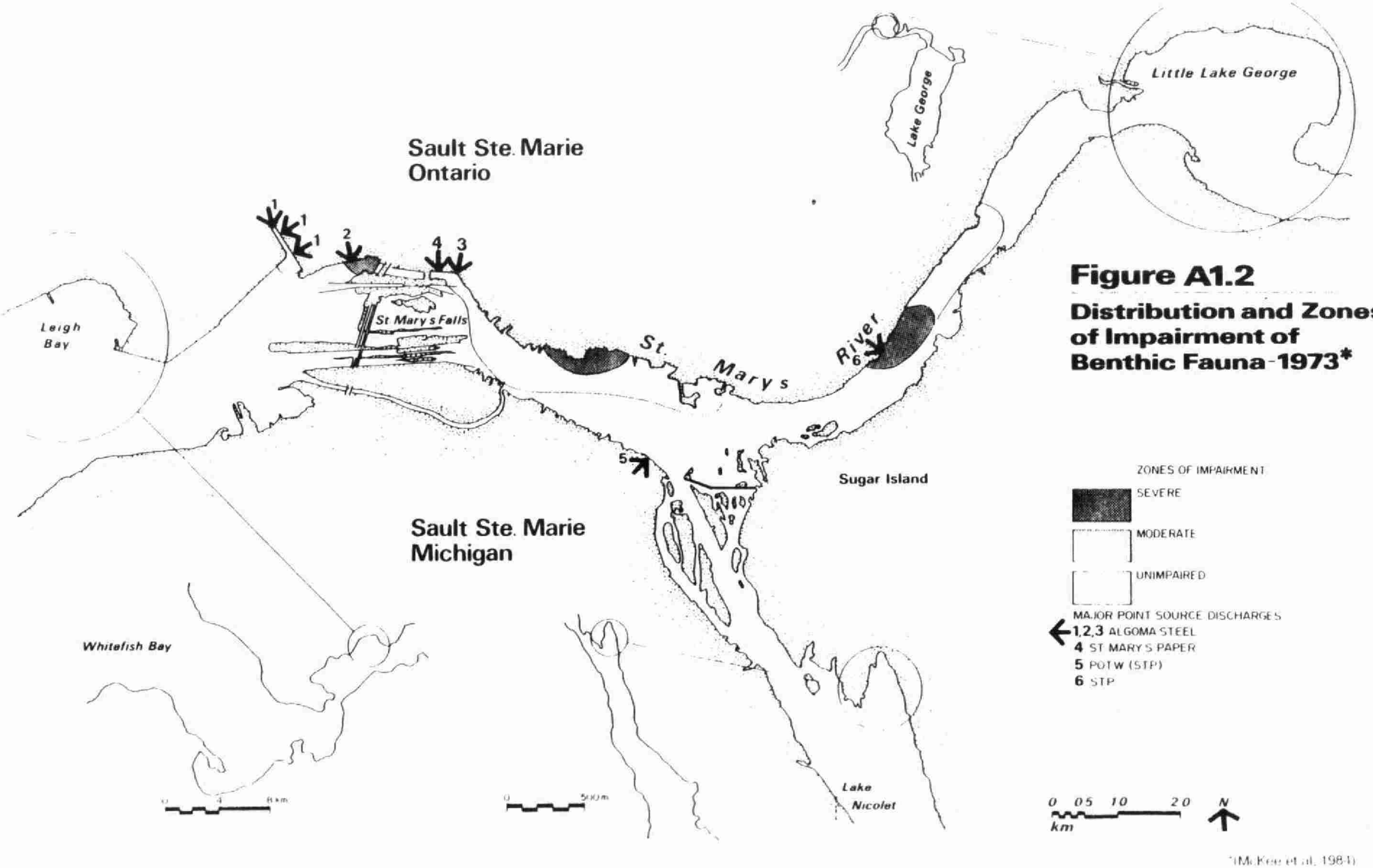


Figure A1.2

Distribution and Zones of Impairment of Benthic Fauna-1973*

*(McKee et al, 1984)

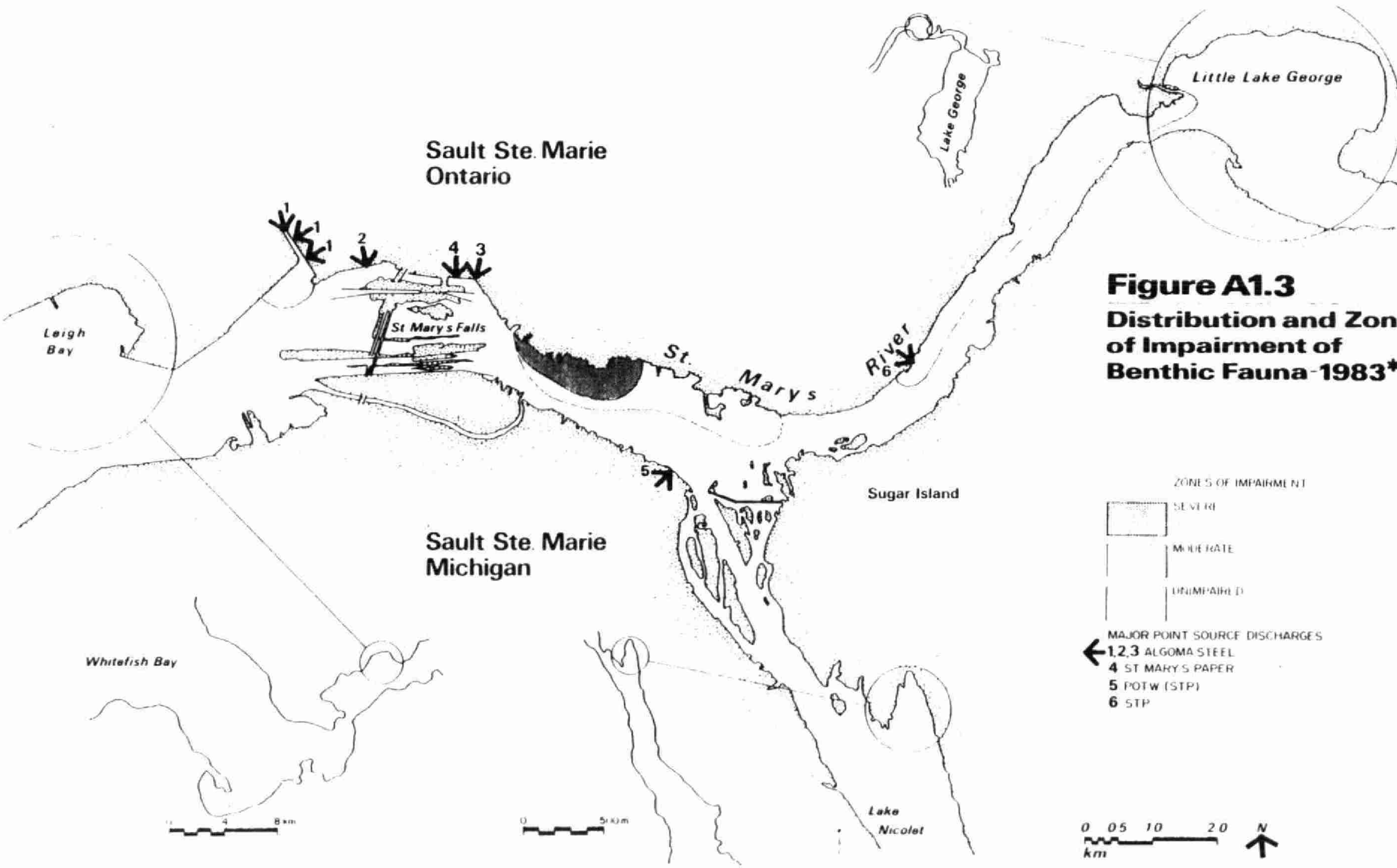


Figure A1.3
Distribution and Zones of Impairment of Benthic Fauna-1983*

*(McKee et al. 1984)

Figure A1.4
Algoma Steel Terminal Basin

Phenols Concentration

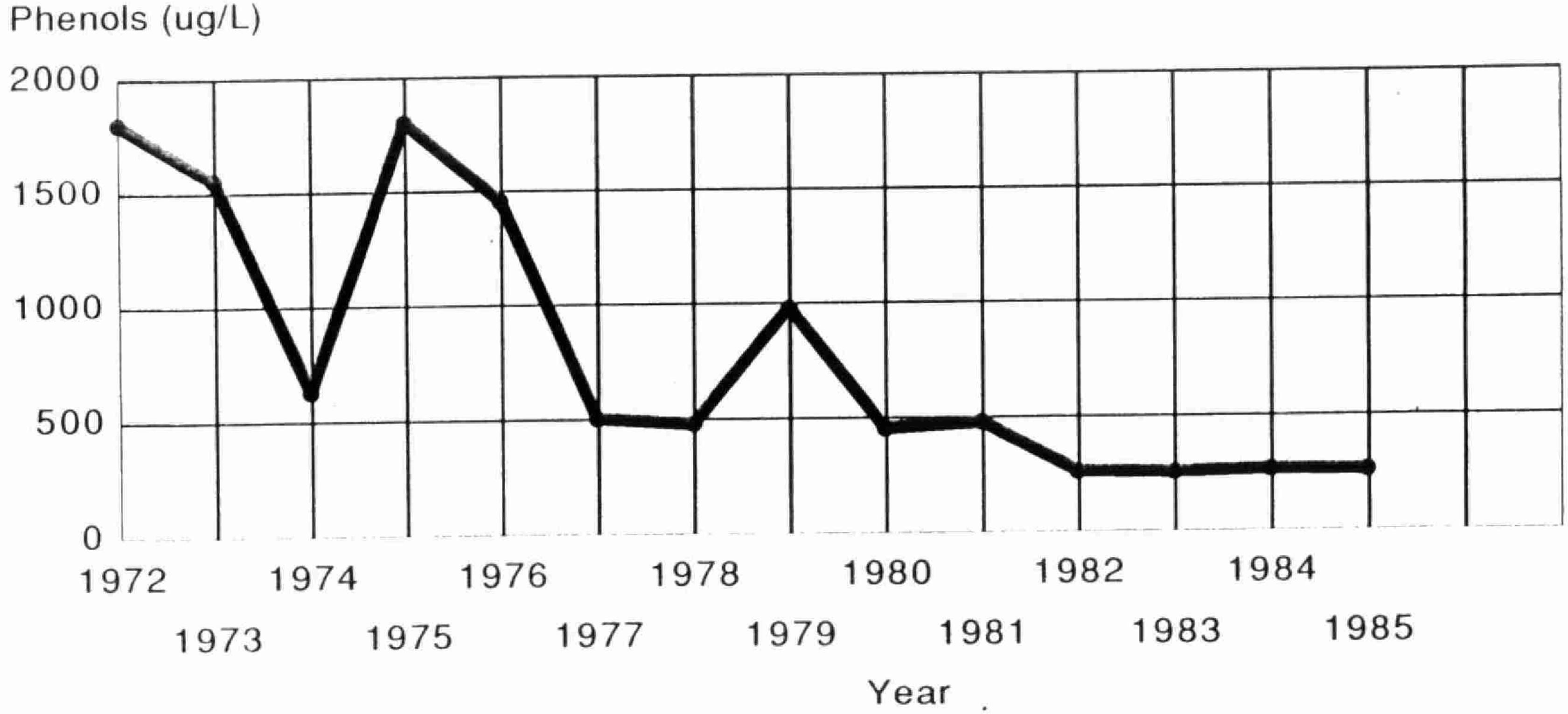


Figure A1.5

Algoma Steel Terminal Basin Effluent

Ammonia Concentration

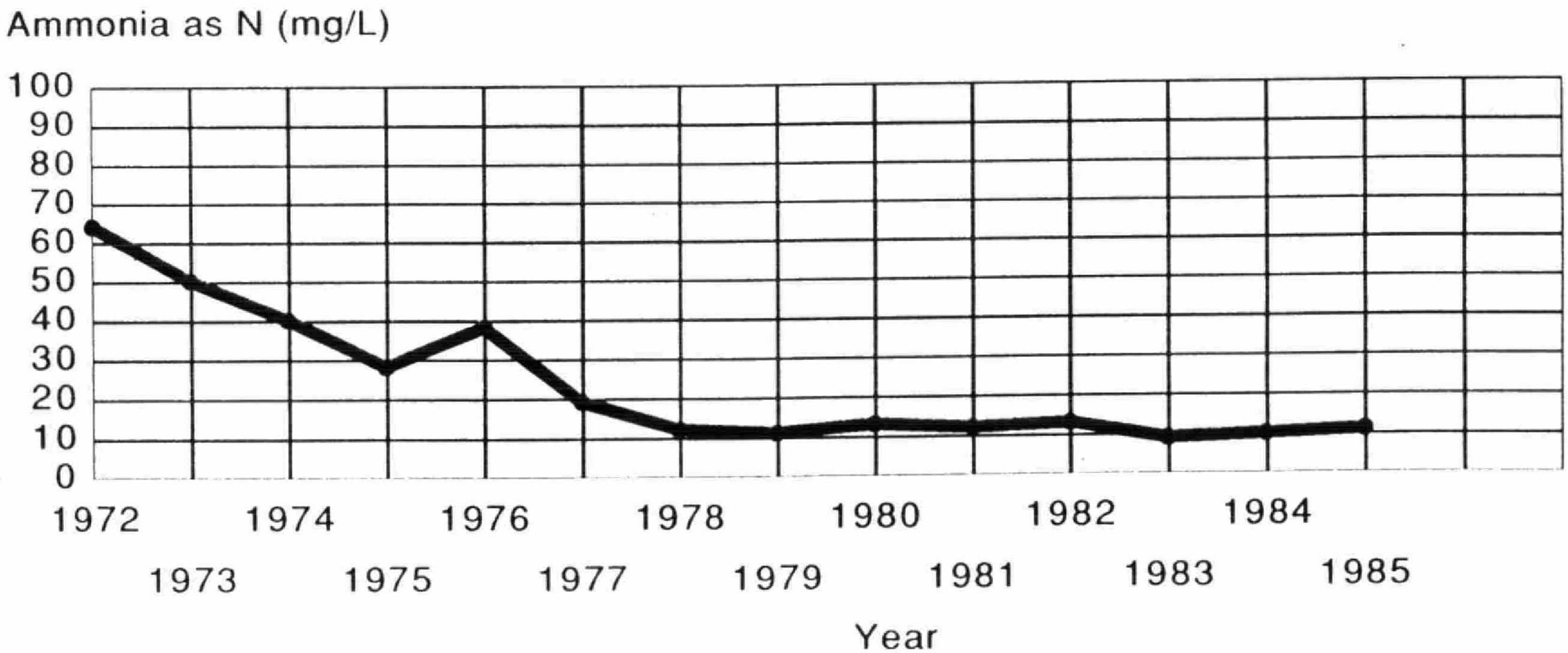


Figure A1.6
Algoma Steel Terminal Basin Effluent

Free Cyanide Concentration

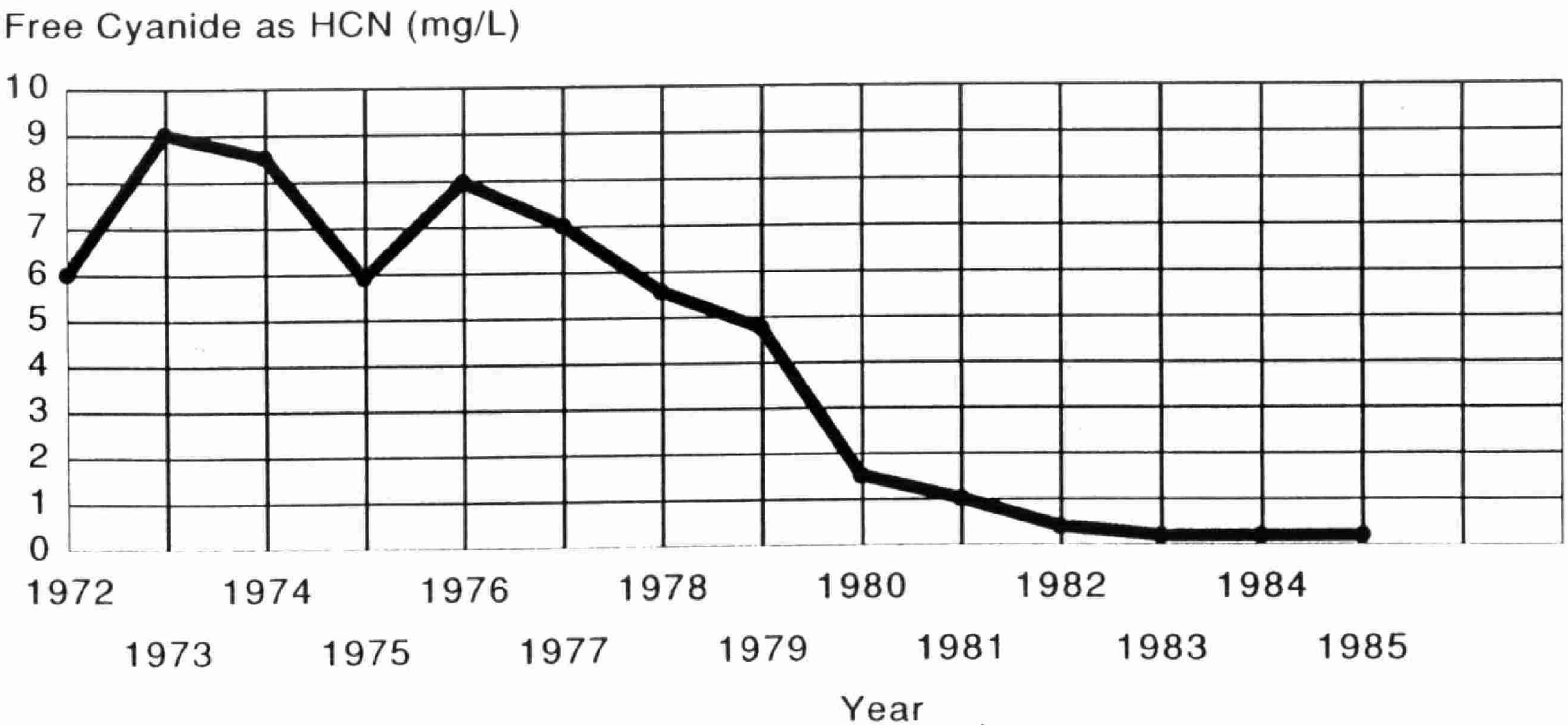


Figure A1.7
Algoma Steel Terminal Basin Effluent

Sulphides Concentration

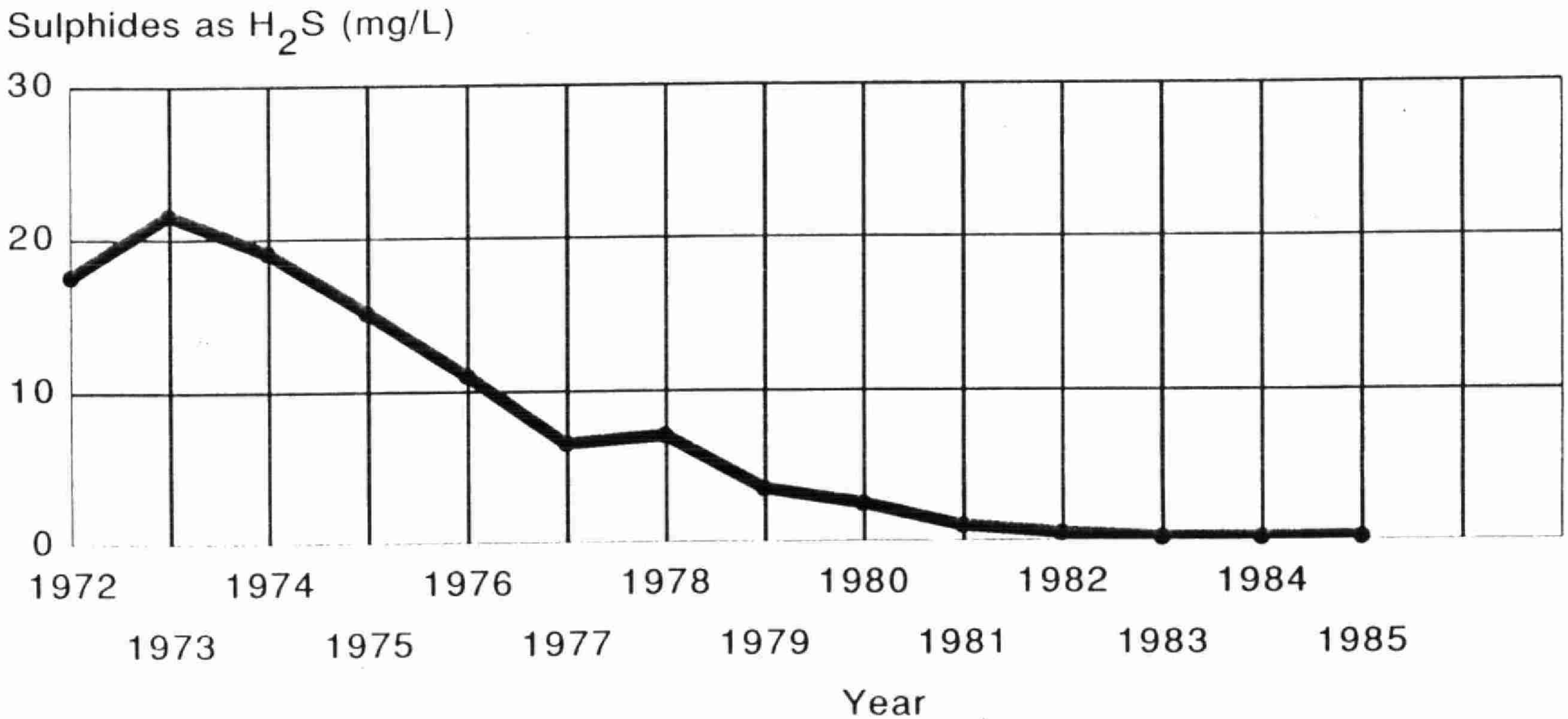
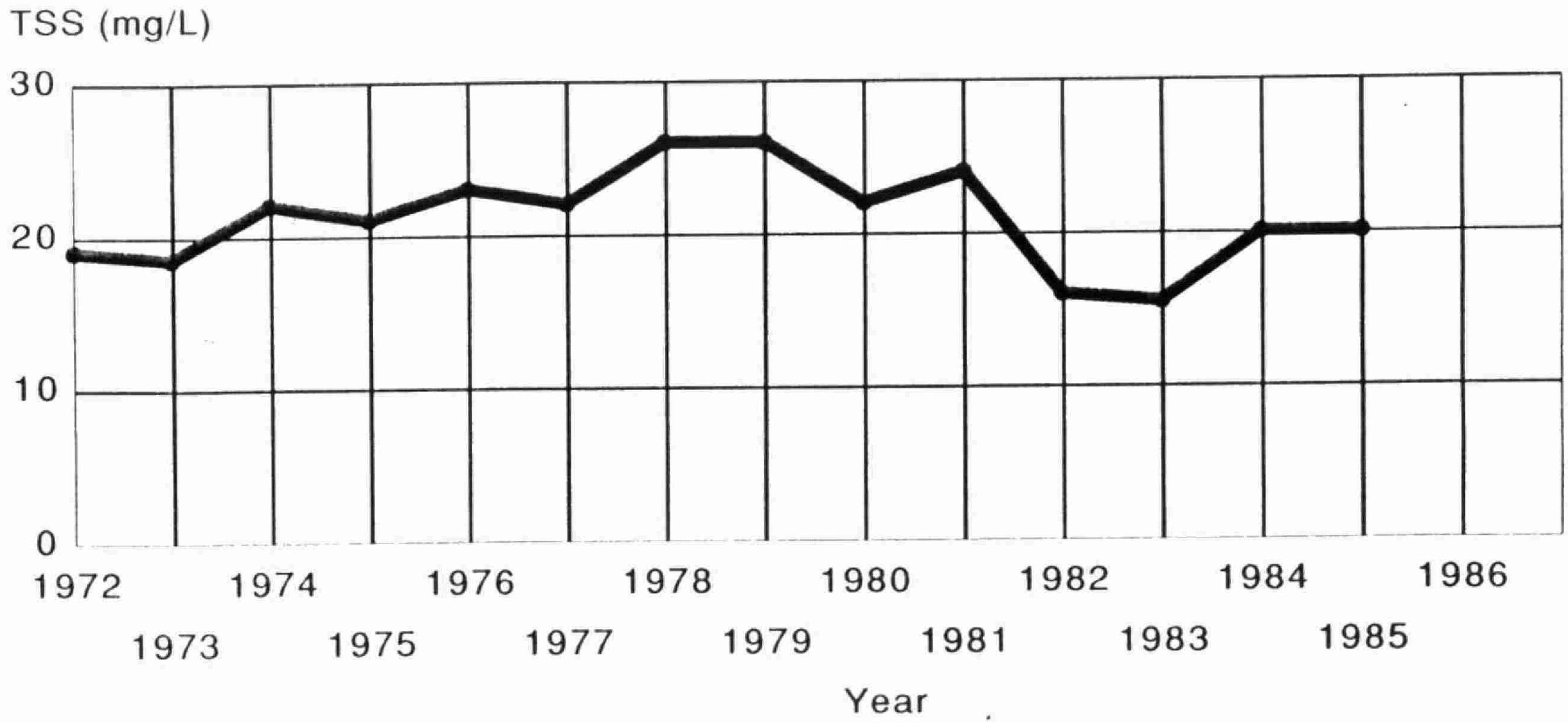


Figure A1.8
Algoma Steel Terminal Basin Effluent

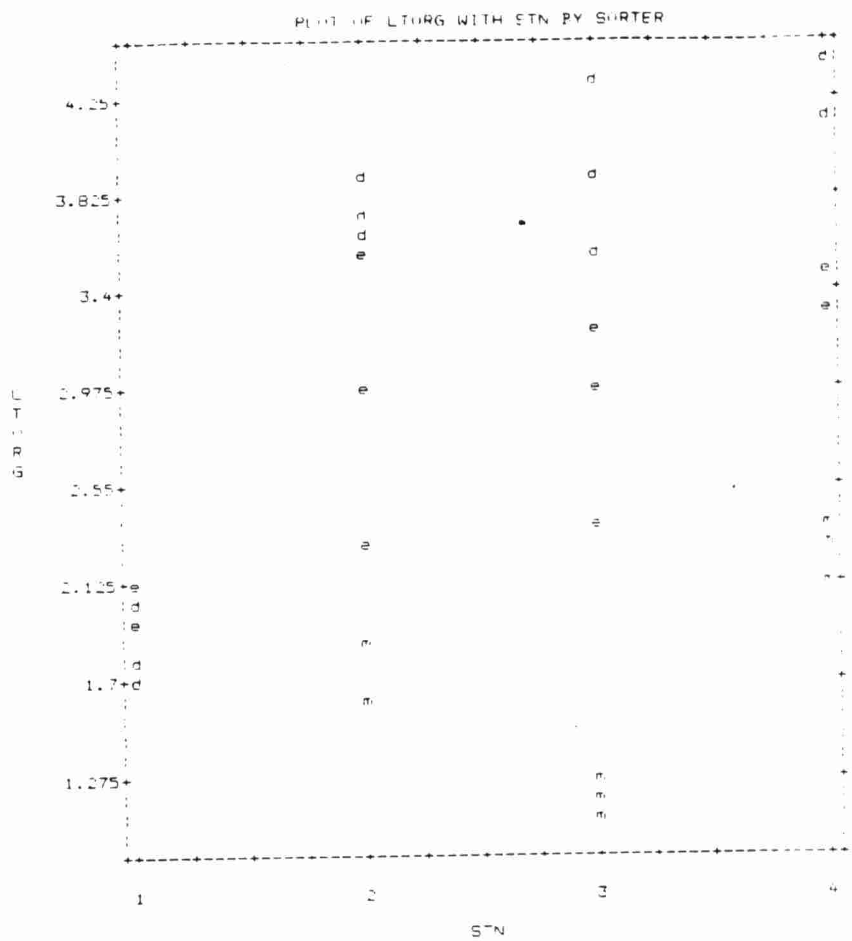
Total Suspended Solids (mg/L)



APPENDIX 2

Comparability of the 1983
and 1985 Benthic Surveys

FIGURE A2.1: SORTER AND TEMPORAL EFFECTS ON LOG TOTAL DENSITY IN CORRESPONDING SAMPLES



Stations

1 118
2 SMD 5.0E-210
3 SMD 5.0E-370
4 SMD 5.0E-520

Sorter

d = sorter DF 1985
e = sorter EJ 1985
m = sorter MS 1983

TABLE A2.1A: DATA FOR EXAMINATION OF SAMPLING METHOD EFFECTS IN 1985 (no./0.05 m^2)

Group	Station	Method	Total Density
1	1	1	11,456
	1	1	4,416
	1	1	4,864
	1	1	3,424
	1	1	12,800
2	1	2	6,656
	1	2	3,840
	1	2	4,288
	1	2	2,560
	1	2	1,792
3	1	3	7,509
	1	3	7,765
	1	3	4,480
	1	3	3,157
	1	3	1,440
4	2	1	1,408
	2	1	1,440
	2	1	704
	2	1	2,496
	2	1	1,024
5	2	2	752
	2	2	232
	2	2	800
	2	2	496
	2	2	400
6	2	3	2,059
	2	3	2,731
	2	3	1,760
	2	3	5,909
	2	3	741
7	3	1	832
	3	1	1,656
	3	1	9,664
	3	1	2,002
	3	1	2,488

TABLE A2.1A: DATA FOR EXAMINATION OF SAMPLING METHOD EFFECTS IN 1985 (no./0.05 m^2)

Group	Station	Method	Total Density
8	3	2	391
	3	2	606
	3	2	145
	3	2	356
	3	2	526
9	3	3	1,902
	3	3	2,177
	3	3	2,894
	3	3	1,312
	3	3	729

Station

1. SMD5.OE-60
2. SMV1.0-2130
3. SMV2.5-1830

Method

1. Ponar grab, 200 mm sieve
2. Ponar grab, 500 mm sieve
3. Airlift sampler, 200 mm sieve

TABLE A2.1B: ANALYSIS OF SAMPLING METHOD EFFECTS (DEVICE AND MESH SIZE) - LOG DENSITY VALUES (no./0.05 m^2 sample) BY STATION AND METHOD (1985 data)

1. Cell Means

Station:	SMD 5.0E-60	SMU 1.0-2130	SMU 2.5-1830	N
	3.65	3.04	3.05	15
Method[1]:	P_{200}	P_{500}	A_{200}	
	3.43	2.93	3.38	15
SMD 5.0E-60	3.81	3.54	3.61	5
SMU 1.0-2130	3.11	2.69	3.33	5
SMU 2.5-1830	3.36	2.56	3.21	5

2. Analysis of Variance

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	5.991	4	1.498	20.211	0.000*
Station	3.712	2	1.856	25.046	0.000*
Method	2.279	2	1.140	15.376	0.000*
Two-Way Interaction					
Station x Method	0.782	4	0.196	2.639	0.050**
Explained	6.774	8	0.847	11.425	0.000*
Residual	2.668	36	0.074		
TOTAL	9.441	44	0.215		

N = Number of samples.

* Significant difference at $p = 0.05$.

** Marginally significant at $p = 0.05$.

1 P_{200} = Ponar grab, 200 um sieve

P_{500} = Ponar grab, 500 um sieve

A_{200} = Airlift sampler, 200 um sieve

TABLE A2.1C: ANALYSIS OF SAMPLING METHOD EFFECTS (DEVICE ONLY) - LOG DENSITY VALUES (no./0.05 m^2 sample) BY STATION AND METHOD (1985 data)

1. Cell Means

Station:	SMD 5.0E-60	SMU 1.0-2130	SMU 2.5-1830	N
	3.71	3.22	3.29	10

Method[1]:	P_{200}	A_{200}	
	3.43	3.38	15
SMD 5.0E-60	3.81	3.61	5
SMU 1.0-2130	3.11	3.33	5
SMU 2.5-1830	3.36	3.21	5

2. Analysis of Variance

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	1.425	3	0.475	5.564	0.005*
Station	1.411	2	0.706	8.266	0.002*
Method	0.014	1	0.014	0.161	0.692
Two-Way Interaction					
Station x Method	0.251	2	0.125	1.469	0.250
Explained	1.676	5	3.336	3.926	0.010*
Residual	2.049	24	0.085		
TOTAL	3.725	29	0.128		

N = Number of samples.

* Significant difference at p = 0.05.

1 P_{200} = Ponar grab, 200 um sieve

P_{500} = Ponar grab, 500 um sieve

A_{200} = Airlift sampler, 200 um sieve

TABLE A2.2A: DATA FOR EXAMINATION OF SORTER EFFECTS ON DENSITY (no./0.05 m^2 sample) IN 1983/85 SAMPLES

Station Sorter	Total Organisms	Major Taxonomic Groups					Log Total Organisms
		Chir	Olig	Poly	Nema	Pele	
1 d	52	4	36	4	0	4	1.72
	56	6	34	2	10	4	1.75
	120	32	56	8	24	0	2.08
2 d	4,496	12	228	4,052	88	8	3.65
	7,888	64	512	6,688	480	0	3.90
	5,697	48	257	4,816	256	112	3.76
3 d	7,680	0	1,024	0	6,656	0	3.89
	19,968	1,024	9,984	0	8,704	0	4.30
	4,096	0	2,048	0	1,792	0	3.61
4 d	26,624	512	19,968	0	6,144	0	4.43
	14,336	512	12,800	0	1,024	0	4.16
	13,312	0	9,216	0	2,560	0	4.12
1 e	91	5	48	16	0	16	1.96
	96	24	56	0	0	8	1.98
	139	16	91	11	11	11	2.14
2 e	3,390	0	320	2,665	85	21	3.53
	1,015	9	209	768	26	4	3.01
	190	9	77	0	34	26	2.28
3 e	256	0	256	0	0	0	2.41
	1,824	192	1,600	0	32	0	3.26
	864	128	608	0	128	0	2.94

TABLE A2.2A: DATA FOR EXAMINATION OF SORTER EFFECTS ON DENSITY (no./0.05 m^2 sample) IN 1983/85 SAMPLES

Station Sorter	Total Organisms	Major Taxonomic Groups Chir	Olig	Poly	Nema	Pele	Log Total Organisms
4 e	3,328	0	2,304	0	1,024	0	3.52
	3,072	0	2,560	0	0	0	3.49
	2,048	0	1,536	0	512	0	3.31
2 m	45.3	2	35	0	0	7	1.66
	40	2	21	0	0	11	1.60
	71.6	7	39	0	0	23	1.85
3 m	20.3	0	19	0	0	0	1.31
	12	0	12	0	0	0	1.08
	17	0	12	0	0	0	1.23
4 m	206.3	3.3	203	0	0	0	2.31
	132.6	2.6	130	0	0	0	2.12
	238.3	5.3	233	0	0	0	2.38

Station

1 118
2 SMD 5.0E-210
3 SMD 5.0E-370
4 SMD 5.0E-520

d = sorter DF 1985 (dissecting microscope used)
e = sorter EJ 1985 (microscope used)
m = sorter MS 1983 (no microscope used)

TABLE A2.2B: ANALYSIS OF SORTER EFFECTS ON TOTAL DENSITY IN 1985 SAMPLES - LOG DENSITY (no./0.05 m^2 sample) BY STATION AND SORTER

1. Cell Means

Station:	118	SMD 5.0E-210	SMD 5.0E-370	SMD 5.0E-520	N
	1.94	3.35	3.40	3.84	6

Sorter[1]:	d	e	N
	3.45	2.82	12
118	1.85	2.03	3
SMD 5.0E-210	3.77	2.94	3
SMD 5.0E-370	3.93	2.87	3
SMD 5.0E-520	4.24	3.44	3

2. Analysis of Variance

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	14.631	4	3.658	36.312	0.000*
Station	12.271	3	4.090	40.606	0.000*
Sorter	2.360	1	2.360	23.431	0.000*
Two-Way Interaction					
Station x Sorter	1.368	3	0.456	4.528	0.018*
Explained	15.999	7	2.286	22.690	0.000*
Residual	1.612	16	0.101		
TOTAL	17.611	23	0.766		

N = Number of samples.

* Significant difference at p = 0.05.

1 d = sorter DF 1985

e = sorter EJ 1985

TABLE A2.3A: DATA FOR EXAMINATION OF TEMPORAL EFFECTS ON TOTAL DENSITY (no./0.05 m^2 sample)

Year	Station	Method	Total Density
1983	1	3	29
	1	3	29
	1	3	27
	2	3	43
	2	3	39
	2	3	71
	3	3	20
	3	3	12
	3	3	17
	4	3	204
	4	3	133
	4	3	238
	5	1	174
	5	1	477
	5	1	624
	6	3	16
	6	3	11
	6	3	77
	7	3	5
	7	3	6
	7	3	5
	8	1	221
	8	1	193
	8	1	237
	9	1	71
	9	1	104
	9	1	75
	10	1	65
	10	1	14
	10	1	53
	11	1	231
	11	1	277
	11	1	431
1985	1	1	11,456
	1	1	4,416
	1	1	4,864
	1	1	3,424
	1	1	12,800
	1	3	7,509
	1	3	7,765
	1	3	4,480
	1	3	3,157
	1	3	1,440

TABLE A2.3A: DATA FOR EXAMINATION OF TEMPORAL EFFECTS ON TOTAL DENSITY (no./0.05 m^2 sample)

Year	Station	Method	Total Density
1985	2	1	4,496
	2	1	7,888
	2	1	5,696
	3	1	7,680
	3	1	25,088
	3	1	4,608
	4	1	33,280
	4	1	14,336
	4	1	11,776
	5	1	20,224
	5	1	18,944
	5	1	17,408
	6	1	3,535
	6	1	442
	6	1	2,095
	7	1	12
	7	1	30
	7	1	36
	8	1	2,502
	8	1	8,474
	8	1	1,040
	9	1	829
	9	1	1,640
	9	1	9,540
	10	1	12,652
	10	1	14,410
	10	1	13,600
	11	1	1,288
	11	1	1,408
	11	1	640

Stations

1 SMD 5.0E-60
2 SMD 5.0E-210
3 SMD 5.0E-370
4 SMD 5.0E-520
5 SMD 5.0E-640
6 SMU 0.5-200
7 SMU 0.5-300
8 SMU 2.5-1300
9 SMU 2.5-1830
10 SMU 2.5-2470
11 SMU 1.0-2130

Method

1 Ponar Grab, 200 um sieve
3 Airlift Sampler, 200 um sieve

Methods 1 and 3 are shown to be comparable in Table A2.1C.

TABLE A2.3B: ANALYSIS OF TEMPORAL EFFECTS ON TOTAL DENSITY, 1983 TO 1985
LOG TOTAL DENSITY (no./0.05 m^2 sample)

1. Cell Means

Station:	SMD 5.0E -60	SMD 5.0E -210	SMD 5.0E -370	SMD 5.0E -520	SMD 5.0E -640	SMU 0.5 -200	SMU 0.5 -300	SMU 2.5 -1300	SMU 2.5 -1800	SMU 2.5 -2500	SMU 1.0 -2260	N
	3.19+	2.73	2.59	3.26	3.42	2.27	1.05	2.89	2.64	2.85	2.75	6

Year:	1983	1985	N
	1.78++	3.54	40
SMD 5.0E-60	1.45	3.71+++	3
SMD 5.0E-210	1.69	3.77	3
SMD 5.0E-370	1.20	3.98	3
SMD 5.0E-520	2.27	4.25	3
SMD 5.0E-640	2.57	4.27	3
SMU 0.5-200	1.38	3.17	3
SMU 0.5-300	0.73	1.37	3
SMU 2.5-1300	2.33	3.45	3
SMU 2.5-1800	1.91	3.37	3
SMU 2.5-2500	1.56	4.13	3
SMU 1.0-2260	2.48	3.02	3

2. Analysis of Variance

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	78.620	11	7.147	95.417	0.000*
Station	22.815	10	2.281	30.458	0.000*
Year	52.704	1	52.704	703.603	0.000*
2-Way Interactions					
Station x Year	8.200	10	0.820	10.947	0.000*
Explained	86.820	21	4.134	55.193	0.000*
Residual	3.820	51	0.075		
TOTAL	90.640	72	1.259		

N : Number of samples.
\+ N = 13
++ N = 33
+++ N = 10
* Significant difference at p = 0.05.

TABLE A2.4: 1983 BENTHIC SPECIES LOADINGS ON PRINCIPAL COMPONENTS

Species	Factor Loadings (Pattern)		% of Variance
	Factor 1	Factor 2	
Hexagenia sp.	0.984	0.000	0.968
Hyallela azteca	0.956	0.000	0.914
Valvata tricarinata	0.951	0.000	0.904
Asellus sp.	0.936	0.349	0.998
Amphipoda sp. indet.	0.935	0.000	0.874
Bezzia complex	0.918	-0.340	0.958
Mystacides sp.	0.918	-0.340	0.958
Oecetis sp.	0.918	-0.340	0.958
Helisoma sp.	0.918	-0.340	0.958
Protanypus sp.	0.918	-0.340	0.958
Hirudinea	0.918	-0.340	0.958
Rhyacodrilus coccineus	0.918	-0.340	0.958
Parachironomus sp.	0.918	-0.340	0.958
Pagastiella sp.	0.918	-0.340	0.958
Caenis sp.	0.884	0.453	0.987
Tanytarsus sp.	0.884	0.453	0.987
Pseudochironomus sp.	0.884	0.453	0.987
Phryganea sp.	0.884	0.453	0.987
Dicrotendipes sp.	0.868	0.000	0.753
Pisidium sp.	0.851	-0.354	0.850
Amnicola limosa	0.798	0.274	0.712
Paramerina sp.	0.785	-0.371	0.754
Polycentropus sp.	0.773	0.300	0.688
Lumbricidae sp. indet.	0.692	-0.360	0.608
Epicocladius sp.	0.692	-0.360	0.608
Spirosperma ferox	0.627	-0.328	0.501
Procladius sp.	0.623	0.000	0.388
Demicryptochironomus sp.	0.612	-0.355	0.501
Phylocentropus sp.	0.269	0.948	0.971
Physa gyrina	0.269	0.948	0.971
Sphaerium sp.	0.269	0.948	0.971
Ischnura sp.	0.269	0.948	0.971
Phaenopsectra sp.	0.436	0.888	0.979
Microtendipes sp.	0.643	0.757	0.986
Polypedilum sp.	0.678	0.726	0.987
Sialis sp.	0.000	0.000	0.000
Molanna sp.	0.000	0.000	0.000
Enallagma sp.	0.000	0.000	0.000
Planaria sp.	0.000	0.000	0.000
Pisidium casteranum	-0.308	0.000	0.095
Sphaerium simile	0.000	0.000	0.000
Pisidium compressum	0.000	0.000	0.000
Thienemannimyia complex	-0.326	0.000	0.106
Tubifex harmoni	0.000	0.000	0.000

TABLE A2.4: 1983 BENTHIC SPECIES LOADINGS ON PRINCIPAL COMPONENTS

Species	Factor Loadings (Pattern) Factor 1	Factor 2	% of Variance
Limnodrilus udekemianus	0.000	0.000	0.000
Immature Tubificidae w/o hair setae	0.000	0.000	0.000
Potamothrix vejdovskyi	0.000	0.000	0.000
Simile striatium	0.000	0.000	0.000
Enchytraeidae	0.000	0.000	0.000
Protoma rubrum	0.000	0.000	0.000
Limnodrilus hoffmeisteri	-0.279	0.000	0.078
Aulodrilus americanus	0.000	-0.321	0.103
Larsia sp.	0.329	-0.456	0.316
Stylodrilus heringianus	0.000	0.000	0.000
Cricotopus sp.	0.000	0.000	0.000
Tanypus sp.	0.000	0.000	0.000
Aulodrilus piqueti	0.000	0.000	0.000
Immature Tubificidae with hair setae	-0.329	0.000	0.108
Vejdovskyella comata	0.000	0.000	0.000
Ablabesmyia sp.	0.000	0.000	0.000
Quistadrilus multisetosus	0.000	0.000	0.000
Glossoscolecidae	0.000	0.000	0.000
Uncinais uncinata	0.000	0.000	0.000
Stylaria lacustris	0.000	0.000	0.000
Specaria josinae	0.000	0.000	0.000
Chironomus sp.	0.000	0.000	0.000
Cladopelma sp.	0.000	0.000	0.000
Cryptochironomus sp.	0.393	-0.460	0.366
Cryptotendipes sp.	0.000	0.000	0.000
Manayunkia speciosa	0.000	0.000	0.000
Slavina appendiculata	0.000	0.000	0.000
Glyptotendipes sp.	0.000	0.000	0.000
Harnischia sp.	0.000	0.000	0.000
Nais pardalis	0.000	0.000	0.000
Lumbriculus variegatus	0.000	0.000	0.000
Gammarus sp.	0.000	0.000	0.000
Paralauterborniella sp.	0.000	0.000	0.000
Nais bretscheri	0.000	0.000	0.000
N. variabilis	0.000	0.000	0.000
Lymnaea sp.	0.000	0.000	0.000
Rheotanytarsus sp.	0.000	0.000	0.000
Stempellina sp.	0.000	0.000	0.000
Stictochironomus sp.	0.000	0.000	0.000
Ripistes parasitica	0.000	0.000	0.000
Isochaetides curvisetosus	0.000	0.000	0.000
Piscicola punctata	0.000	0.000	0.000
Heterotrissocladius sp.	0.000	0.000	0.000
Orthocladius sp.	0.000	0.000	0.000

TABLE A2.4: 1983 BENTHIC SPECIES LOADINGS ON PRINCIPAL COMPONENTS

	Factor Loadings (Pattern)		
Species	Factor 1	Factor 2	% of Variance
Psectrocladius sp.	0.000	0.000	0.000
Thienemanniella sp.	0.000	0.000	0.000
Diamesa sp.	0.000	0.000	0.000
Monodiamesa sp.	0.000	0.000	0.000
Crangonyx sp.	0.000	0.000	0.000
Collembola sp. indet.	0.000	0.000	0.000
Potthastia sp.	0.000	0.000	0.000
Ephemera sp.	0.000	0.000	0.000
Hydra sp.	0.000	0.000	0.000
Paraleptophlebia sp.	0.000	0.000	0.000
Valvata sincera	0.000	0.000	0.000
Stenonema sp.	0.000	0.000	0.000
Ephemeroptera sp. indet.	0.000	0.000	0.000
Pristina osborni	0.000	0.000	0.000
Nais barbata	0.000	0.000	0.000
Piquetiella sp.	0.000	0.000	0.000
Agraylea sp.	0.000	0.000	0.000
Oxyethira sp.	0.000	0.000	0.000
Ceraclea sp.	0.000	0.000	0.000
Lirceus sp.	0.000	0.000	0.000
Nectopsyche sp.	0.000	0.000	0.000
Nematoda sp. indet.	0.000	0.000	0.000
Pristina foreli	0.000	0.000	0.000
Ptilostomis sp.	0.000	0.000	0.000
Stylaria flossularis	0.000	0.000	0.000
Campeloma decisum	0.000	0.000	0.000
Aulodrilus pluriseta	0.000	0.000	0.000
Hydracarina sp. indet.	0.000	0.000	0.000
Baetis sp.	0.000	0.000	0.000
% of Variance	23.364	9.395	

See plot of species loadings on Factors 1 and 2 in Figure A2.2.

TABLE A2.5: 1985 BENTHIC SPECIES LOADINGS ON PRINCIPAL COMPONENTS

Species	Factor Loadings (Pattern) Factor 1	Factor 2	% of Variance
Valvata sincera	0.985	0.000	0.970
Pisidium sp.	0.975	0.000	0.951
Tanytarsus sp.	0.975	0.000	0.951
Pagastiella sp.	0.969	0.000	0.939
Bezzia complex	0.964	0.000	0.929
Microtendipes sp.	0.961	0.000	0.924
Polycentropus sp.	0.957	0.000	0.916
Cryptotendipes sp.	0.953	0.000	0.908
Hexagenia sp.	0.952	0.000	0.906
Paralauterborniella sp.	0.951	0.000	0.904
Glyptotendipes sp.	0.948	0.000	0.899
Caenis sp.	0.948	0.000	0.899
Nectopsyche sp.	0.948	0.000	0.899
Sialis sp.	0.948	0.000	0.899
Campeloma decisum	0.944	0.000	0.891
Mystacides sp.	0.936	0.000	0.876
Aulodrilus pluriseta	0.929	0.000	0.863
Psectrocladius sp.	0.843	0.000	0.711
Harnischia sp.	0.834	0.344	0.814
Amnicola limosa	0.796	0.000	0.634
Stempellina sp.	0.785	0.459	0.827
Aulodrilus americanus	0.678	0.510	0.720
Crictopus sp.	0.674	0.000	0.454
Lirceus sp.	0.593	0.447	0.551
Lymnaea sp.	0.000	0.948	0.899
Monodiamesa sp.	0.000	0.934	0.872
Ephemera sp.	0.000	0.889	0.790
Rheotanytarsus sp.	0.353	0.701	0.616
Oecetis sp.	0.000	0.700	0.490
Specaria sp.	0.613	0.629	0.771
Nematoda sp. indet.	0.000	-0.614	0.377
Immature Tubificidae w/o hair setae	0.000	-0.574	0.329
Baetis sp.	0.000	0.625	0.391
Campeloma decisum	0.000	0.625	0.391
Stylaria fossularis	0.000	0.625	0.391
Ceraclea sp.	0.000	0.625	0.391
Nais bretscheri	0.000	0.625	0.391
Thienemanniella sp.	0.000	0.625	0.391
Pristina foreli	0.000	0.625	0.391
Stenonema sp.	0.000	0.625	0.391
Isochaetides cirvisetosus	0.000	0.625	0.391
Piquetiella sp.	0.000	0.625	0.391

TABLE A2.5: 1983 BENTHIC SPECIES LOADINGS ON PRINCIPAL COMPONENTS

Species	Factor Loadings (Pattern) Factor 1	Factor 2	% of Variance
Gammarus sp.	0.000	0.625	0.391
Ephemeroptera sp. indet.	0.000	0.625	0.391
Stictochironomus sp.	0.000	0.625	0.391
Hyallela azteca	0.000	0.632	0.399
Parachironomus sp.	0.000	0.564	0.318
Uncinais uncinata	0.000	0.575	0.331
Paraleptophlebia sp.	0.000	0.575	0.331
Pseudochironomus sp.	0.000	0.575	0.331
Stylaria lacustris	0.000	0.575	0.331
Epoicocladius sp.	0.000	0.569	0.324
Hydra sp.	0.000	0.595	0.354
Heterotrissocladius sp.	0.000	0.629	0.396
Crangonyx sp.	0.000	0.515	0.265
Ptilostomis sp.	0.000	-0.388	0.151
Helisoma sp.	0.000	-0.428	0.183
Hydracarina sp. indet.	0.000	-0.428	0.183
Limnodrilus udekemianus	0.000	-0.418	0.175
Quistadrilus multisetosus	0.000	-0.418	0.175
Agraylea sp.	0.000	-0.418	0.175
Ablabesmyia sp.	0.000	-0.476	0.227
Limnodrilus hoffmeisteri	0.000	-0.450	0.203
Asellus sp.	0.000	-0.282	0.080
Polpedilum sp.	0.504	0.000	0.254
Dicrotendipes sp.	0.000	-0.413	0.171
Nais variabilis	0.000	-0.504	0.254
Larsia sp.	0.000	0.000	0.000
Piscicola punctata	0.000	0.000	0.000
Potthastia sp.	0.000	0.000	0.000
Physa gyrina	0.000	0.406	0.165
Oxyethira sp.	0.000	0.413	0.171
Enchytraeidae sp. indet.	0.685	0.000	0.469
Sphaerium sp.	0.000	0.620	0.384
Phaenopsectra sp.	0.540	0.507	0.549
Glossoscolecidae sp. indet.	0.555	0.000	0.308
Slavina appendiculata	0.000	-0.279	0.078
Orthocladius sp.	0.000	0.000	0.000
Cladopelma sp.	0.000	0.000	0.000
Cryptochironomus sp.	0.330	0.000	0.109
Procladius sp.	0.448	0.000	0.201
Aulodrilus piqueti	0.000	0.329	0.108
Thienemannimyia sp.	0.389	0.286	0.233
Demicryptochironomus sp.	0.000	0.000	0.000

TABLE A2.5: 1983 BENTHIC SPECIES LOADINGS ON PRINCIPAL COMPONENTS

Species	Factor Loadings (Pattern) Factor 1	Factor 2	% of Variance
Manayunkia speciosa	0.000	0.000	0.000
Ripistes parasitica	0.000	0.000	0.000
Pristina osborni	0.000	0.000	0.000
Stylodrilus heringianus	0.000	0.000	0.000
Vejdovskyella comata	0.000	0.000	0.000
Nais barbata	0.000	0.000	0.000
N. pardalis	0.000	0.000	0.000
Diamesa sp.	0.466	-0.314	0.316
Spirosperma ferox	0.000	-0.445	0.198
Prostoma rubrum	0.265	-0.364	0.203
Chironomus sp.	0.000	0.000	0.000
Immature Tubificidae with hair setae	0.000	-0.388	0.151
Collembola sp. indet.	0.000	0.000	0.000
Lumbricilus variegatus	0.000	0.000	0.000
Pisidium casertanum	0.000	0.000	0.000
Protanypus sp.	0.000	0.000	0.000
Sphaerium simile	0.000	0.000	0.000
Enallagma sp.	0.000	0.000	0.000
Ishnura sp.	0.000	0.000	0.000
Sphaerium striatium	0.000	0.000	0.000
Tanypus sp.	0.000	0.000	0.000
Pisidium compressum	0.000	0.000	0.000
Paramerina sp.	0.000	0.000	0.000
Valvata tricarinata	0.000	0.000	0.000
Rhyacodrilus coccineus	0.000	0.000	0.000
Lumbricidae sp. indet.	0.000	0.000	0.000
Molanna sp.	0.000	0.000	0.000
Tubifex harmani	0.000	0.000	0.000
Phryganea sp.	0.000	0.000	0.000
Phylocentropus sp.	0.000	0.000	0.000
Hirudinea sp. indet.	0.000	0.000	0.000
Amphipoda sp. indet.	0.000	0.000	0.000
Potamothrix vejdovskyi	0.000	0.000	0.000
% of Variance	23.196	18.632	

See plot of species loadings on Factors 1 and 2 on Figure A2.2.

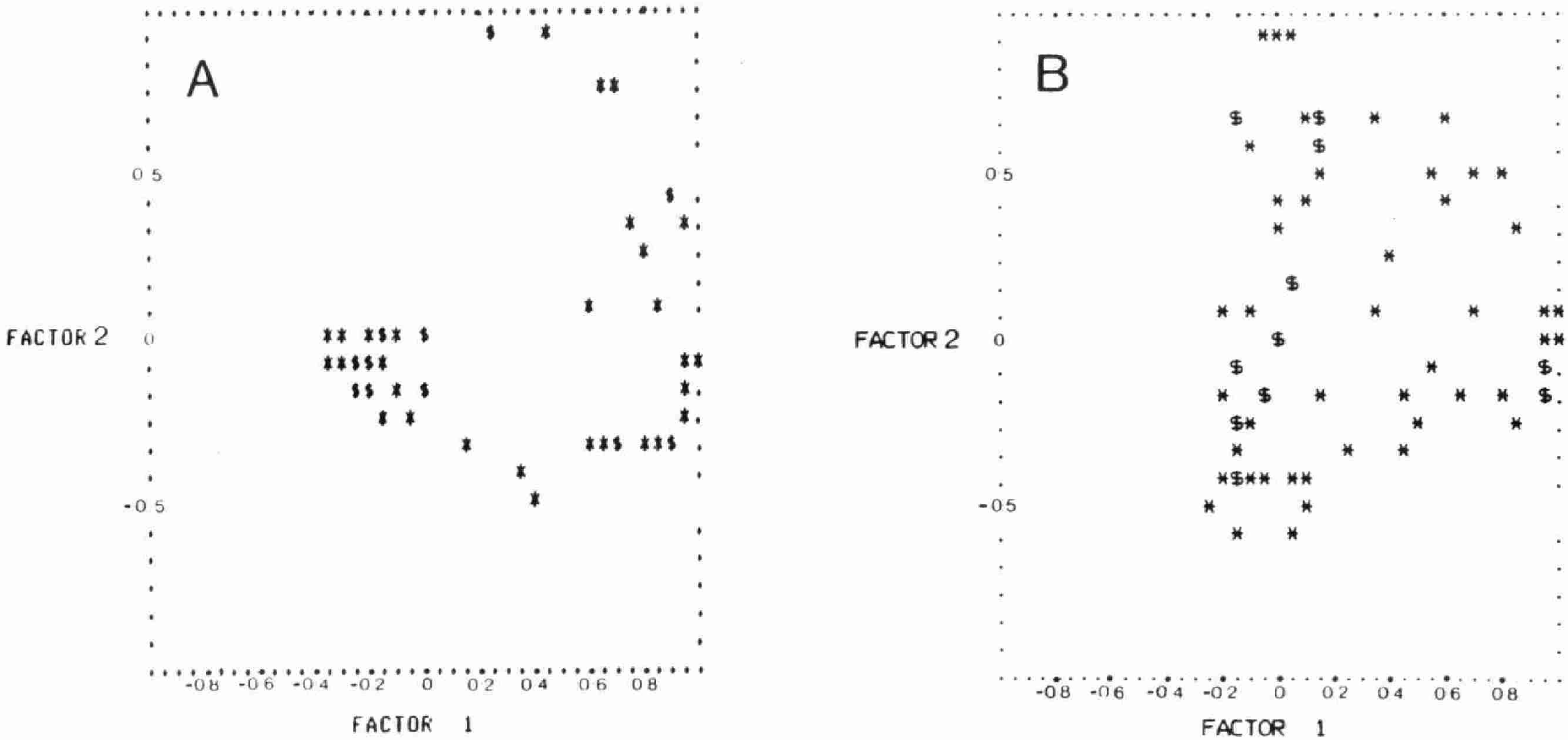


FIGURE A2.2: PLOTS OF SPECIES LOADINGS ON PRINCIPAL COMPONENT FACTORS:
A - 1983, B - 1985, * - Single Species, $ = Multiple Species

APPENDIX 3

Cluster Analysis of 1985 Benthic Data

TABLE A3.1: CONCORDANCE OF CLUSTER ANALYSIS SOLUTIONS USING DIFFERENT CLUSTERING METHODS

Cluster No.	Station No.	Cluster Assignments by Each Method					
		WARD'S	WAVG	BAVG	KMEANS(7)	KMEANS(8)	GHOW
1	81	1	3	1	3	8	6
	82	1	3	1	3	8	6
	85	1	3	*	3	8	3
	92	1	3	*	3	8	3
	93	1	3	1	3	8	6
	95	1	3	1	3	8	6
	101	1	3	1	3	3	6
	84	1	3	1	3	8	6
	105	1	3	1	3	8	6
	96	1	3	1	3	1	6
	98	1	3	1	3	8	6
	104	1	3	1	3	8	6
	97	1	3	1	3	1	6
	80	1	3	1	3	8	6
	SMD 5.0E-60	1	3	1	3	1	6
	106	1	3	1	3	1	6
2	SMD 6.4E-350	2	3	1	3	1	1
	SMD 6.4E-570	2	3	1	3	1	1
	SMD 5.0E-210	2	3	1	3	1	1
	SMD 6.4E-420	2	3	1	3	1	1
	SMD 6.4E-490	2	3	1	3	1	1
	120	2	3	1	3	1	1
	113	2	3	*	3	1	5
3	100	3	1	1	3	6	4
	102	3	1	1	3	6	4
	SMD 2.6-950	3	1	1	3	6	1
	86	3	1	1	3	6	4
	SMD 5.0E-640	3	1	*	5	6	4
	87	3	1	*	5	6	4
	SMD 5.0E-370	3	1	1	3	6	1
	88	3	1	*	3	6	4
	SMD 1.2-840	3	1	*	5	6	4
4	SMU 0.5-300	4	1	1	3	6	1
	116	4	1	1	3	6	1
	115	4	1	1	3	6	1
	118	4	1	1	3	6	1
	SMD 0.8-600	4	1	1	3	6	1
	127	4	1	1	3	6	4
	107	4	1	1	3	6	1
	SMU 1.0-2130	4	1	1	3	6	1
	119	4	1	1	3	6	1
	117	4	1	1	3	6	1
	SMD 5.0E-520	4	1	1	3	6	4

TABLE A3.1: CONCORDANCE OF CLUSTER ANALYSIS SOLUTIONS USING DIFFERENT CLUSTERING METHODS

Cluster No.	Station No.	Cluster Assignments by Each Method					
		WARD'S	WAVG	BAVG	KMEANS(7)	KMEANS(8)	GHOW
5	123	5	3	2	2	3	2
	121	5	3	2	3	8	2
	SMU 2.5-1830	5	3	2	2	8	2
	126	5	3	2	2	3	2
	SMU 2.5-1300	5	3	2	2	8	2
	SMU 0.5-200	5	1	2	3	8	2
	124	5	1	2	3	1	2
	99	5	3	1	3	8	6
6	108	6	3	3	2	8	3
	109	6	2	3	3	8	3
	110	6	2	3	3	8	3
	90	6	2	3	7	8	3
	111	6	2	3	2	8	3
	103	6	2	3	4*	8	3
	83	6	2	3	3	8	3
	94	6	2	3	3	8	3
	91	6	3	3	3	8	3
	114	6	3	*	3	7	3
	SMU 2.5-2470	6	3	*	2	8	5
	112	6	2	*	3	8	5
	SMD 1.2-15	6	1	*	6	4*	5
	SMD 2.6-40	6	3	*	1*	5*	5
7	125	7	3	*	2	2	2
	122	7	2	*	5	2	7
	SMD 6.4E-280	7	1	*	7	3	7
	89	7	1	*	7	3	7
	SMU 1.8-1690	7	1	*	7	2	7

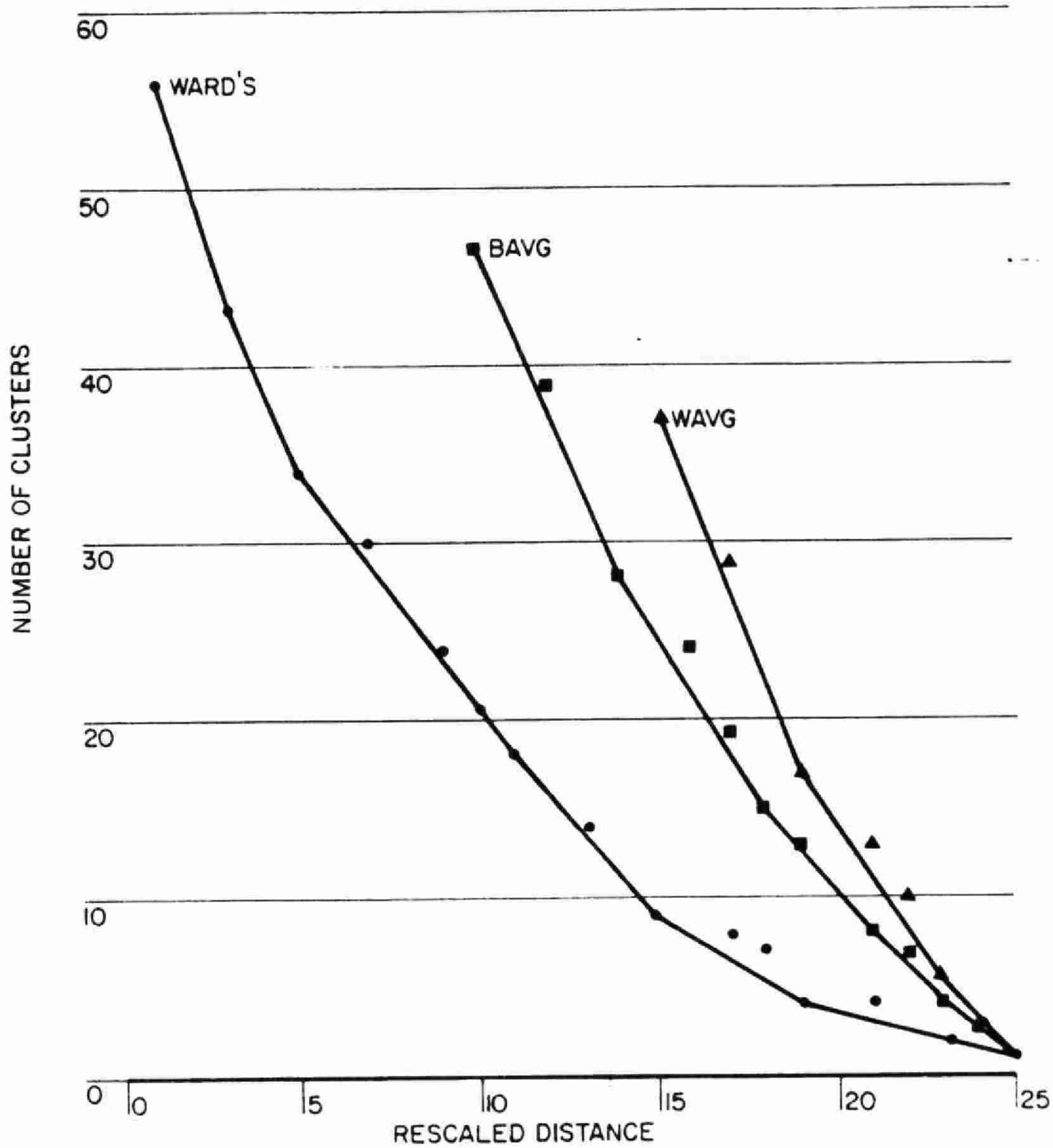
* Single station cluster.

Key to Methods:

WARD: Hierarchical Agglomeration - Ward's Method
WAVG: Hierarchical Agglomeration - Within Group Average Link
BAVG: Hierarchical Agglomeration - Between Group Average Link
KMEANS(7): K-Means Partition - 7 Cluster Solution
KMEANS(8): K-Means Partition - 8 Cluster Solution
GHOW: Hierarchical Polythetic Division Howard-Harris Method

Figure A3.1

Structural Comparison of Cluster Analysis Solutions Obtained by Different Methods



WARD'S: Ward's Method (Squared Euclidean Distance Measure)
BAVG: Between Group Average Link (Euclidean Distance Measure)
WAVG: Within Group Average Link (Euclidean Distance Measure)

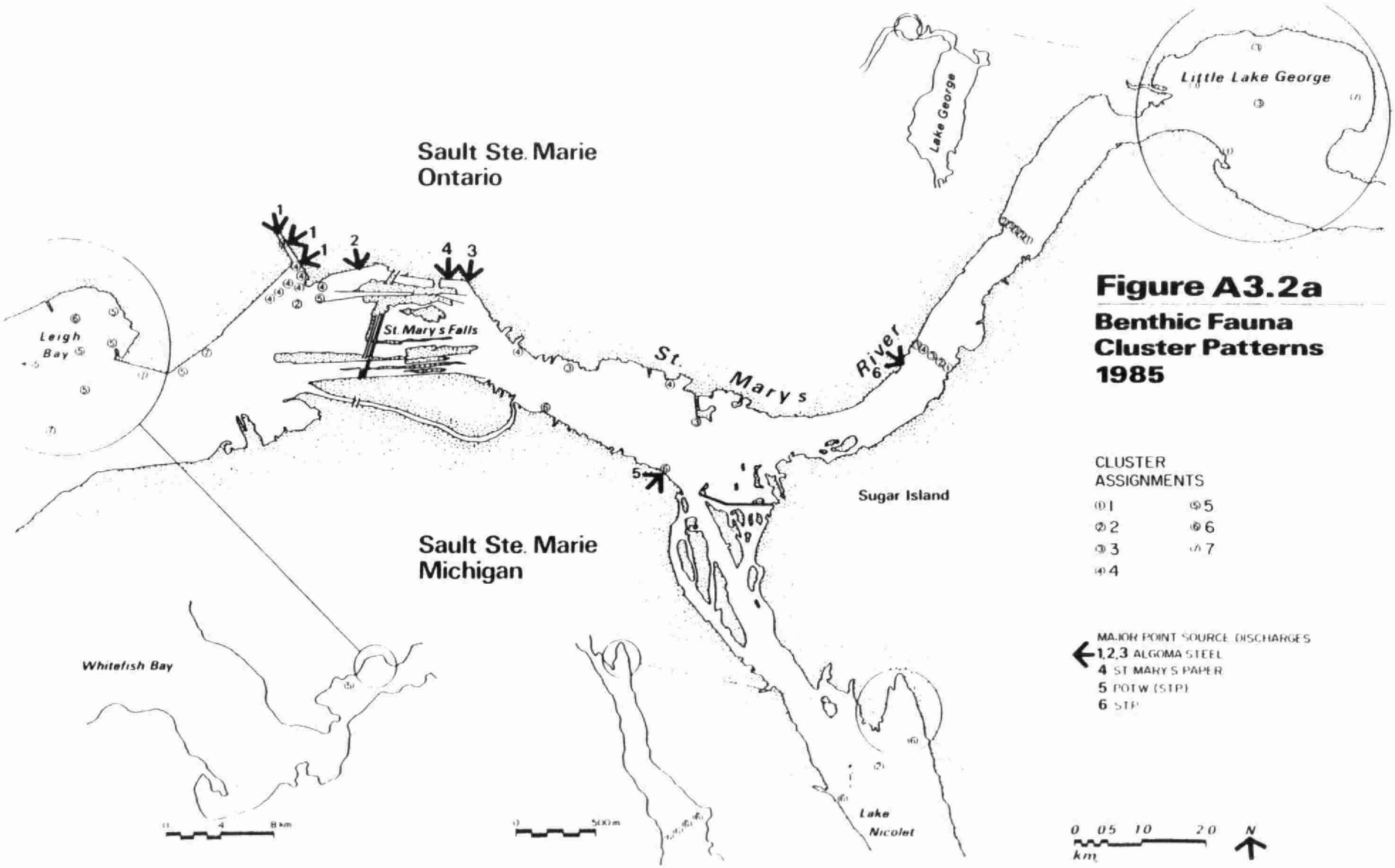


Figure A3.2a
Benthic Fauna Cluster Patterns 1985

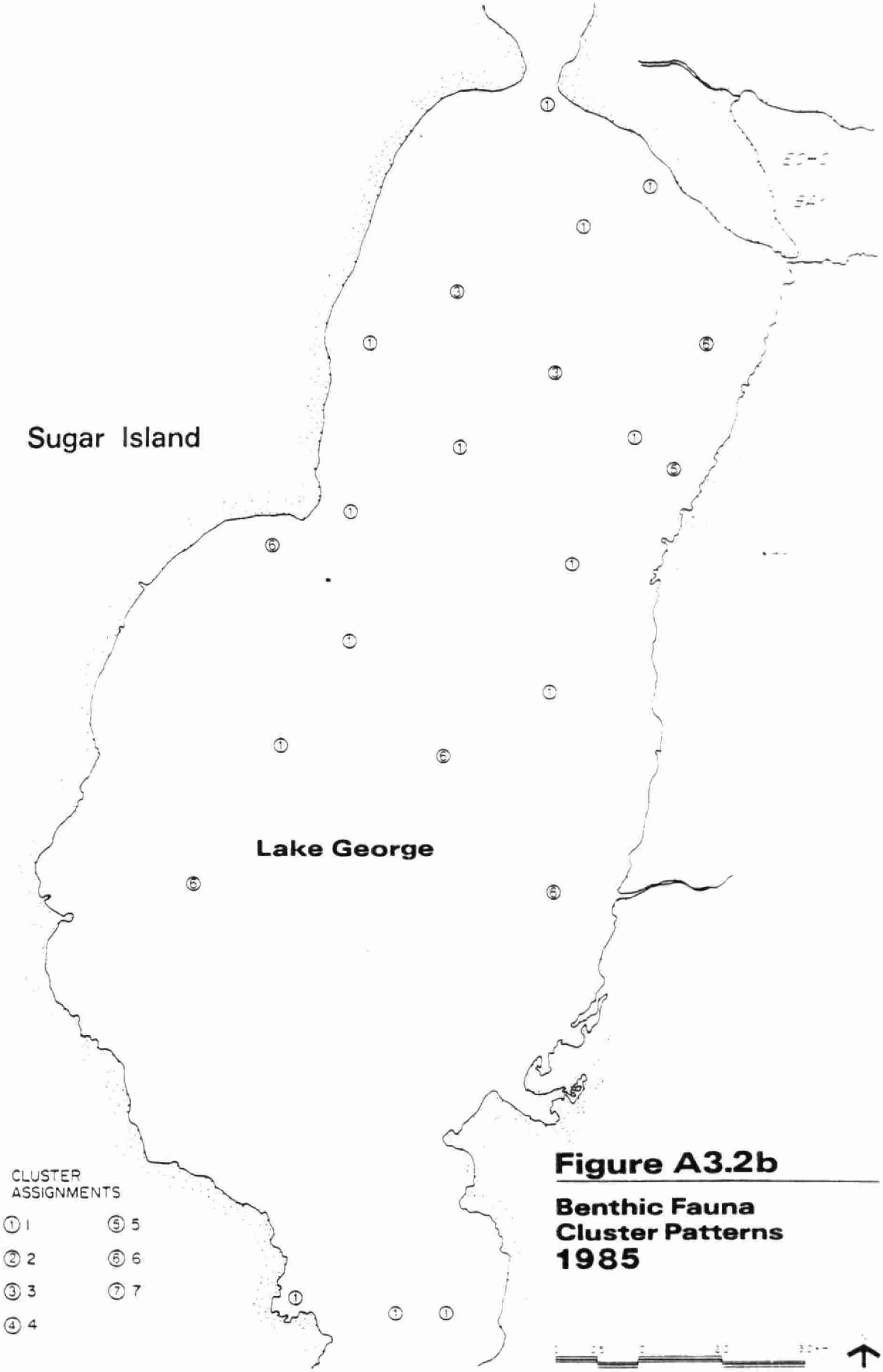


Figure A3.2b

Benthic Fauna Cluster Patterns 1985

ADWX